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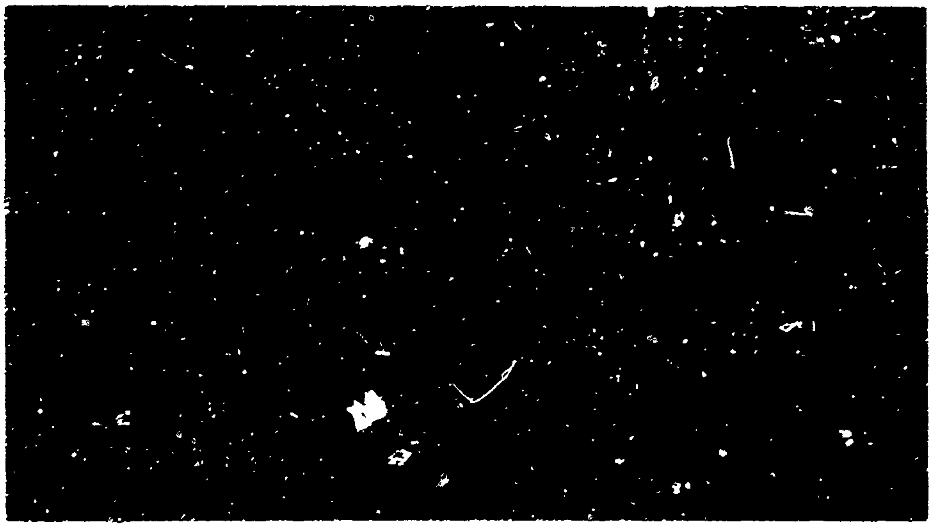

UNIDYNAMICS PHOENIX DIVISION

UNIVERSAL MATCH CORPORATION

CONTRACT NUMBER DA-36-039 SC-87362

SIGNAL CORPS TECHNICAL REQUIREMENT SCL 7564

DATED 11 AUGUST 1960

RESEARCH AND DEVELOPMENT

DIRECTED TOWARD THE DEVELOPMENT OF

GAS GENERATORS

FINAL REPORT

Document No. D63-702

The object of this program is to develop gas generators covering an output range of 50 to 10,000 cc, with means of incorporating delay times from electrical pulse to propellant ignition of 0 -.4 seconds, with operating temperatures from 65° F to 212° F and storage temperatures from -80° F to 300° F.

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TABLE OF CONTENTS

PURPOSE

The purpose of this project is to develop improved gas generators to activate zinc-silver oxide batteries employing the Signal Corps metal-tube electrolyte-reservoir activating system. It is desired to replace the gas generators presently employed for this task with a unit which has a longer shelf life over a wider range of environmental conditions.

The project consists of three major tasks: (1) design and development of gas generators, (2) environmental testing, and (3) reports, conferences, and shipment of prototype units.

ABSTRACT

This report describes the work conducted under Contract DA 36-039 SC-87362 with the U.S. Signal Supply Agency, consisting of a propellant investigation, gas generator design and development, and development and environmental testing of gas generators.

The results of the propellant investigation indicated that one commercial propellant, B.F. Goodrich C-501, and a Unidynamics formulation N-1825B, exhibited the most satisfactory thermal stability and reproducible gas output and pressure-vs-time characteristics after conditioning at 300° F for 168 hours. However, N-1825B propellant was selected for use in the gas generator since it is easily furnished with center perforations and exhibits a low content of hydrochloric acid in its exhaust gases.

During gas generator design and development, sealed matches with delays of 0, 0.2, and 0.4 seconds were developed which provided outputs sufficient to ignite the propellant charge. In addition, theoriginal design of the gas generators was modified to incorporate a grain trap nozzle and provide base plug end ignition. A satisfactory test fixture was fabricated for pressure-vs-time and output testing.

Testing of the gas generators demonstrated that the hardware design and propellant formulation were satisfactory for the application. However, two problem areas were encountered: (1) Ignition of the 0.2 and 0.4-second delay matches was marginal at -60° F, and (2) delay burn times exceeded the specified $\pm$ five percent over the temperature range -60° F to 165° F. In addition, extensive development work beyond the scope of this program would be required to verify the specified $\pm$ five percent variation in peak pressur over the operating temperature range.

CONFERENCES

Progres Review Meeting No. 1 was held on July 20, 1961 at the U. S. Army Signal R & D Laboratory for the purpose of program planning. Agreement was reached that Unidynamics would initially concentrate its effort on the development of 150-cc. 950-cc, and 8000-cc gas generators with 0, .2, and .4 second delays to cover the 50 cc to 10,000 cc output range and 0-2 second delay time as specified in Signal Corps Technical Requirement SCL 7564.

Progress Review Meeting No. 2 was held on September 18 and 19, 1961, at Unidynamics' Chemical Operations, to discuss technical aspects of the contract. Approval of the test fixture design was received and agreement was reached for Unidynamics to continue propellant investigations.

Progress Review Meeting No. 3 was held at the U. S. Army Signal R & D Laboratory on 8 November 1961 to discuss work accomplishment during the first quarter of the contract. It was mutually agreed that Unidynamics would: (1) utilize a sealed electric match to obtain front end ignition of the propellant grain, (2) continue the propellant investigation with efforts directed toward developing the grain for the gas generator, and (3) continue the market survey for a commercially available propellant.

Progress Review Meeting No. 4 was held at Unidynamics on 6 and 7 February 1962 to discuss work accomplishments during second quarter of the contract and future plans. It was mutually agreed that Unidynamics would:

a. attempt to reduce the time-to-peak pressure of propellant composition N-1825,

b. rerun tests for the HCl content of N-1825 combustion gases,

c. commence work on shock and vibration of N-1825,

d. determine temperature change of propellant grains upon removal from elevated or reduced temperatures, to determine whether or not conditioning of the test fixture is required,

e. record propellant grain weights for each gas generator tested, and

f. test a commercially available propellant.

Progress Review Meeting No. 5 was held at the U. S. Army Signal R & D Laboratory on 4 May 1962 to discuss work accomplishments during third quarter of the contract and future plans. The items discussed are as follows:

a. The cause of the erratic test results with respect to thermal stability and pressure-vs-time testing of three lots of modified N-1825 propellant was determined to be in the mixing procedure. Unidynamics indicated that a controlled processing procedure would correct the difficulties.

b. The B. F. Goodrich propellant, C-501, passed all tests to which it had been subjected. However, the HCl content in the combustion gases of this propellant was approximately double that of N-1825 propellant.

c. The test results of a Unidynamics' contract for fabrication and testing of 1200 cc gas generators was discussed. These gas generators utilized an exhaust nozzle and ignition by a Unidynamics' sealed match located at the base plug of the gas generator.

Since the exhaust nozzle allowed the propellant to burn at a constant pressure, the reproducibility of the time-to-peak pressure was improved. Unidynamics suggested that the Signal Corps utilize this design. It was mutually agreed that 50 percent of the gas generators to be tested during the remainder of the program would utilize exhaust nozzles and base plug ignition, and 50 percent would utilize exhaust end ignition without a nozzle to allow a direct comparison of results. After reviewing the test results, the Signal Corps would submit the preferred design to Unidynamics prior to fabrication of the 240 gas generators of Note 1 of the contract.

d. The Signal Corps indicated that the desired nominal delay times for the delay sealed matches were 200 and 400 milliseconds. It was agreed that all firing tests following other environments would be conducted at -65° F in the future.

e. Unidynamics desired to utilize N-1825 propellant in the gas generators; however, this would require approximately two months extension to the contract. The Signal Corps considered this approach feasible. Should attempts to stabilize N-1825 propellant prove unsuccessful, the B. F. Goodrich C-501 propellant would be utilized.

Progress Review Meeting No. 6 was held at Unidynamics' Crab Orchard Operations on 22 - 23 January 1963. The purpose of this meeting was to enable Mr. A. Hack, of Signal Corps to witness the testing of four 8000 cc and two 950 cc gas generators.

a. Due to the failure of one 950cc gas generator to fire, Unidynamics incorporated a slight modification to the gas generator ignition

system (confirmed by Unidynamics TWX, dated 24 January 1963, to Captain R. Obach, U.S. Army Signal Supply Agency).

b. Based on the modification and rework of existing units, the following schedule to complete was submitted:

(1) Complete rework of existing units - 18 February 1963.

(2) Complete environmental and functional testing - 15 March 1963.

(3) Submit draft of final report - 29 March 1963

Progress Review Meeting No. 7 was held at Unidynamics' Crab Orchard Operations during May 1963. Concurrently with this meeting, Mr. A. Hack of Signal Corps witnessed the completion of environmental and functional testing of the 36 modified gas generators. It was mutually agreed between Signal Corps and Unidynamics that:

(1) The epoxy change on all units, which resulted from the high temperature soak, was not cause for retest or design rejection.

(2) Leakage of ignition material during vibration was not cause for retest since sufficient ignition material remained in the units to assure proper ignition although the end crimp and epoxy closure was weak.

(3) Grain traps blowing out of units was not cause for retest since the grain traps were cleaned and new plastic disks were potted in place to assure that no orifice holes were plugged.

(4) The removal of the valve nozzle on the closed bomb test fixture would eliminate the shock wave shown the pressure-vs-time oscilloscope traces, thus providing true ignition spike recording.

1. FACTUAL DATA

1.1 General. Unidynamics conducted a vendor survey and a literature survey to determine the feasibility of a high-temperature stable propellant to meet the requirements of Signal Corps Technical Requirement SCL 7564. The literature survey indicated five possible propellant formulations which might yield a product with the requisite characteristics. A test fixture was designed and fabricated and the five formulations were tested using production gas generators and sealed matches. Following completion of development and environmental testing, one formulation designated N-1825B was selected because it best met requirements, and gas generators were fabricated using that formulation.

1.2 Propellant Investigation. Unidynamics conducted a propellant investigation in two separate areas: (1) a vendor survey; and, (2) a literature survey. A survey of major producers in the propellant industry was conducted to determine whether or not a suitable propellant was commercially available. A literature survey on propellant constituent fuel binders, oxidizers, and additives -- was conducted to ascertain which combinations would optimally fulfill Signal Corps Technical Requirement SCL 7564.

.2.1 Vendor Survey. An initial survey of the propellant industry was conducted using Signal Corps Technical Requirement SCL 7564 as the procurement specification. The results of this survey showed that no propellant was commercailly available which would meet the thermal stability requirement (300° F for one week) and exhibit flame temperature and burn rate characterisitcs compatible with battery activation applications

1.2.1.1 Subsequent to the unsuccessful initial vendor survey, Unidynamics prepared a propellant procurement specification with the following requirements:

a. The propellant must be capable of withstanding, without degradation, 168 hours (7 days) storage at 300° F.

b. The burn rates to peak pressure must be reproducible within plus or minus 5% over a temperature range of -65° F to 212° F and after (a).

c. The propellant must give reproducible peak pressures and time-to-peak pressures within plus or minus 5% after being subjected to 5 cycles of thermal shock, each cycle consisting of 3 hours at -80°F followed immediately by 3 hours at 212° F.

d. The propellant must produce the rated volume of gas plus or minus 5% after being subjected to any or all of the temperatures discussed above.

e. Propellant must have physical characteristics such that it will withstand vibration of 35 g's, 5-2000 cps, after being stabilized at -80° F to 212° F, when loaded in gas generators, in addition to shock of 250 g's with a rise time of 6 to 11 milliseconds under the same conditions.

f. The propellant must produce a minimum amount of slag.

g. The propellant must have a minimum of 300 cc/gm gas output.

h. The flame temperature must be no greater than 3600° F. (Isobaric)(T_c)

i. The composition of the propellant must be supplied and certified.

1.2.1.2 B. F. Goodrich had a propellant (C-501) which they felt would meet these requirements; however, their bid was received after the 15 January 1962 cutoff date. Unidynamics had already begun work on its five basic propellants when B. F. Goodrich's late bid arrived. Unidynamics therefore continued its propellant development. Also, B. F. Goodrich's propellant was classified confidential, although it proved to be similar to Unidynamics N-1801 propellant with the exception that C-501 contains no additive.

1.2.2 Literature Survey. Concurrent with the vendor survey, Unidynamics conducted an extensive literature survey to determine which fuel binders, oxidizers, and other additives could be utilized in the manufacture of a suitable propellant. This survey yielded the following possible constituents for such a propellant:

a. Fuel binders: (1) polybutadiene-acrylic acid; and, (2) polyurethane

b. Oxidizers: (1) ammonium perchlorate

c. Additives: (1) oxamide; (2) nitroguanidine; (3) guanidine picrate; and, (4) carbon black.

1.2.2.1 Fuel Binders. The fuel binders considered for use in a propellant with the requisite characteristics were the polysulfides, polyvinyl chloride, polyfluorocarbons, epoxies, silicones, acrylonitriles, acrylates, polybutadiene-acrylic acid copolymers, and polyurethanes. Polybutadiene-acrylic acid and polyurethane were selected for further evaluation because of their characteristics as follows:

a. Stability for extended periods at 300° F

b. Satisfactory physical properties at reduced temperatures

c. No detectable slag deposits in the exhaust stream.

Polybutadiene-acrylic acid is commercially available in liquid and solid forms under the trade names of Hycar 2000 x 131 and Hycar 1000 x 103 respectively. Polyurethane is commercially available under the trade name of Estane 5720 x 5. Hycar 2000 x 131 and Estane 5720 x 5 require curing catalysts to harden the propellant grains and prevent flaking. This necessitates extrusion of the grains soon after mixing. However, Hycar 1000 x 103 requires no curing agent and may be stored indefinitely before it is extruded in grain formations.

1.2.2.2 <u>Oxidizers.</u> The oxidizers considered for use were ammonium nitrate, potassium perchlorate, and ammonium perchlorate. Ammonium perchlorate was selected for further evaluation as an oxidizer because of its characteristics as follows:

a. Thermal stability (decomposes at 516° F)

b. Ease of ignition when used in a propellant

c. High burning rate

d. Clean burning (produces no harmful slag)

e. Non-hygroscopicity.

1.2.2.3 <u>Additives.</u> Additives considered were oxamide, nitroguanidine, guanidine picrate, and carbon black. Desirable effects of an additive are: (1) increased gas output; (2) reduced flame and gas temperature; (3) more uniform combustion; and (4) improved ignition characteristics. A description of each of the additives selected for evaluation follows:

a. Oxamide is a non-explosive with (1) excellent thermal stability (melts at 783° F), and (2) a highly endothermic decomposition. The endothermic property of oxamide results in a lowered flame temperature, but may also extinguish the burning propellant in concentrations above five percent.

b. Nitroguanidine is an explosive with (1) fair thermal stability (melts at 450° F), (2) over 1000 cubic centimeters-per-gram gas output, and (3) a low flame temperature. It will sustain combustion in a propellant in concentrations above 40 percent.

c. Guanidine picrate is an explosive with (1) good thermal stability (melts at 531° F), (2) a theoretical gas output of over 1000 cubic centimeters-per-gram, and (3) a low flame temperature. Guanidine picrate sustains combustion well in a propellant in concentrations up to 40 percent. Despite the excellent physical properties of guanidine picrate, it is not a commercially available compound at present, and its use required the preparation of a manufacturing procedure.

d. Carbon black darkens the propellant grain and results in (1) improved ignition characteristics, and (2) uniform combustion.

1.3 <u>Propellant Formulations.</u> Using various combinations of the binders, additives, and the ammonium perchlorate oxidizer selected in the literature survey, Unidynamics prepared five basic propellant formulations (See Table I). Preliminary thermal stability tests were conducted to determine which formulations would meet the minimum thermal requirement of 168 hours storage at 300° F with no effect on stability.

TABLE I

PROPELLANT FORMULATIONS

a. Propellant N-1801 (solid polybutadiene-acrylic acid binder)

NH_4ClO_4	66.50%
Hycar 1000 X 103	19.00%
Nitroguanidine	14.00%
Carbon Black	0.50%
	100.00%

b. Propellant N-1811 (liquid polyurethane binder)

NH_4ClO_4	71.80%
Estane 5720 X 5	22.00%
1, 4-Butanediol	0.18%
Trimethylol Propane	0.44%
Triethanolamine	0.08%
Oxamide	5.00%
Carbon Black	0.50%
	100.00%

c. Propellant N-1816 (liquid polybutadiene-acrylic acid binder)

NH_4ClO_4	80.00%
Hycar 2000 X 131	15.00%
Epon 828	4.00%
Carbon Black	1.00%
	100.00%

d, Propellant N-1817 (liquid polybutadiene-acrylic acid binder)

NH_4ClO_4	65.00%
Hycar 2000 X 131	15.00%
Nitroguanidine	15.00%
Epon 828	4.00%
Carbon Black	1.00%
	100.00%

e. Propellant N-1825

Ammonium Perchlorate	48.5 %
Hycar 1000 X 103	15.0 %
Guanidine Picrate	36.0 %
Carbon Black	0.5 %
	100.0 %

1.3.1 Constituent Variation. The five basic propellants are discussed in the following paragraphs:

1.3.1.1 N-1801 was an ammonium perchlorate-polybutadiene-acrylic acid propellant containing nitroguanidine as a coolant and carbon black as an ignition aid and burning rate stabilizer. The basis for evaluating this propellant system first was its anticipated satisfactory thermal stability, high gas output, lack of slag formation, and simplicity and safety of processing. This propellant is readily ignited and burns very evenly.

1.3.1.2 N-1811 was an ammonium perchlorate-polyurethane composition. This composition was prepared for a thermal stability comparison with the ammonium perchlorate-polybutadiene-acrylic acid system (N-1801). Also, composition N-1811 was prepared using oxamide coolant in order to obtain some idea of the percentage of this additive which could be incorporated without extinguishing the flame or preventing ignition. Composition N-1811 is ignited with some difficulty and burns more slowly than composition N-1801.

1.3.1.3 N-1816 and N-1817 were prepared and tested to determine the relative stability of an ammonium perchlorate-polybutadiene-acrylic acid propellant with and without nitroguanidine additive. This was considered necessary due to the known marginal stability of nitroguanidine at 300° F. In order to facilitate processing, a liquid-type polybutadiene-acrylic acid was used.

1.3.1.4 N-1825 was prepared to determine whether or not the use of guanidine picrate would result in greater thermal stability than the N-1801 and N-1816 compositions containing nitroguanidine, and better burning characteristics than composition N-1811 containing oxamide.

1.3.2 Preliminary Testing. Thermal stability tests were conducted on the five propellant formulations selected. The purpose was to determine whether decomposition occurs when the formulations are stored at 300° F for one week. Test procedure and results follow:

1.3.2.1 Test Procedure and Results. Two of the samples were tested in sealed containers to determine (1) whether or not the test container would be ruptured by pressure, and (2) the effect of limited atmospheric oxygen on decomposition. After testing, it was found that all of the sealed containers had developed minute leaks at the seals, thereby allowing weight loss by the escape of decomposition gases. However, the exclusion of oxygen by the nearly sealed containers did reduce the decomposition rate, indicating that atmospheric oxygen did increase decomposition of the open test samples. Table II shows the results of these tes... The tests were conducted according to the following procedure:

STEP	PROCEDURE
1.	Weigh four samples (approximately 2 grams each).
2.	Place two samples in ointment tubes and crimp the ends.
3.	Place two samples in open containers.
4.	Place all four containers in an oven and let remain for one week at 300° F.

TABLE II

THERMAL STABILITY OF PROPELLANTS

CONDUCTED AT 300° F FOR 168 HOURS

Propellant	No. Samples		Wt. Loss Open Containers	Wt. Loss Closed Containers*
	Open	Closed	Average (%)	Average (%)
N-1801	2	2	3.35	2.04
N-1811	2	2	4.55	2.32
N-1816	2	2	5.86	5.46
N-1817	2	2	12.47	9.57
N-1825	2	2	2.98	2.02

* Broken seals noted at end of test.

5. Weigh each of the samples on a Gram-atic balance and determine the percentages of weight loss.

1.3.2.2 <u>Discussion of Thermal Stability Test Results.</u> From the thermal stability test results of the five basic propellant formulations shown in Table II, the following data was obtained:

a. After exposure to 300° F for 168 hours, propellants N-1801 and N-1825 lost less weight than the other formulations tested. These formulations are somewhat harder after 168 hours at 300° F, but examination did not disclose any change in burning rate or ignition sensitivity. This was determined by visual comparison of samples burned in open containers.

b. Propellant formulation N-1811 is flexible and tough prior to 300° F temperature conditioning, but becomes soft and tears easily after extended thermal stability testing. The weight loss data of Table II, in conjunction with the evidence of serious deterioration of physical properties, indicates that composition N-1811 is not suitable for the Signal Corps application.

c. The weight loss data of Table II shows that the addition of 15 percent nitroguanidine (formulation N-1817) results in almost twice as much weight loss as when no nitroguanidine is used (formulation N-1816). The thermal stability tests also showed that liquid polybutadiene-acrylic acid with Epon 828 curing agent is not as thermally stable as the solid, higher-molecular-weight type Hycar 1000 x 103.

1.3.2.3 Based on the above results, it was concluded that further testing should be limited to the N-1801 and N-1825 basic propellant formulations or variations of these.

1.4 Gas Generator Design and Development. Concurrent with the investigation for a thermally stable propellant, work was conducted on the design and development of three gas generators with outputs of 150 cc, 950 cc, and 8000 cc having the following operational features:

a. Component material, igniter and delays capable of withstanding temperatures from -80° F to 300° F for extended periods.

b. Ignition delays of 0, 0.2, and 0.4 second.

c. Dual ignition characteristics to assure reliability.

d. Interchangeability of components wherever possible.

In addition to the development of the gas generators, a test fixture was designed, and sealed electric matches having delays of 0, 0.2, and 0.4 second were developed and tested.

1.4.1 Gas Generator Design. The basic design for the three gas generators is shown in Figure 1.

1.4.1.1 The main features of this design are (1) a base-end ignition system consisting of two sealed matches, and (2) a propellant grain trap. Two sealed matches are employed redundantly to assure reliable functioning. In addition, the flash output of the sealed match is greatly improved over that of the Atlas M-103 Match currently used in several gas generators (See Figure 2). The propellant grain trap serves the dual purpose of insuring that

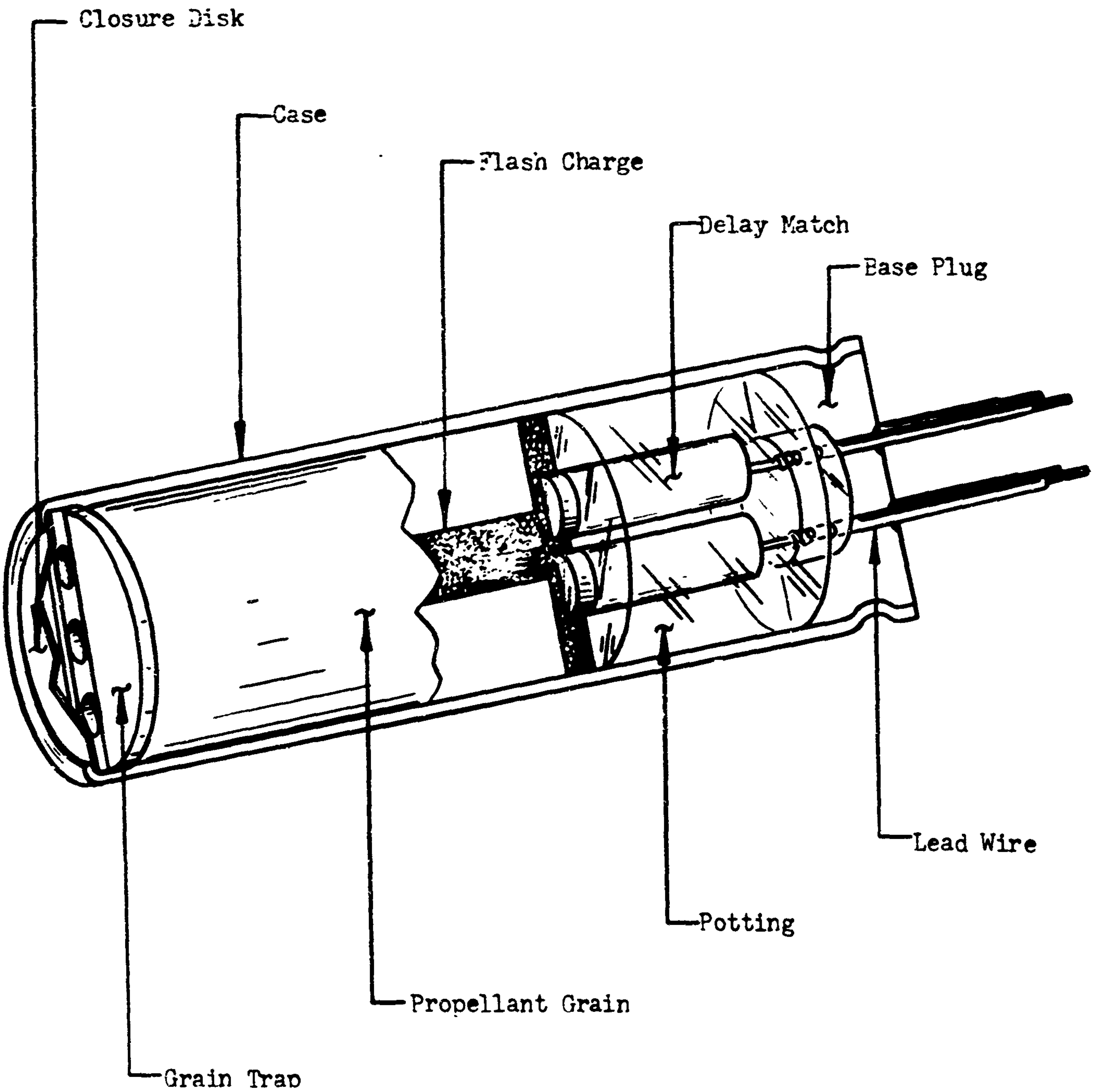
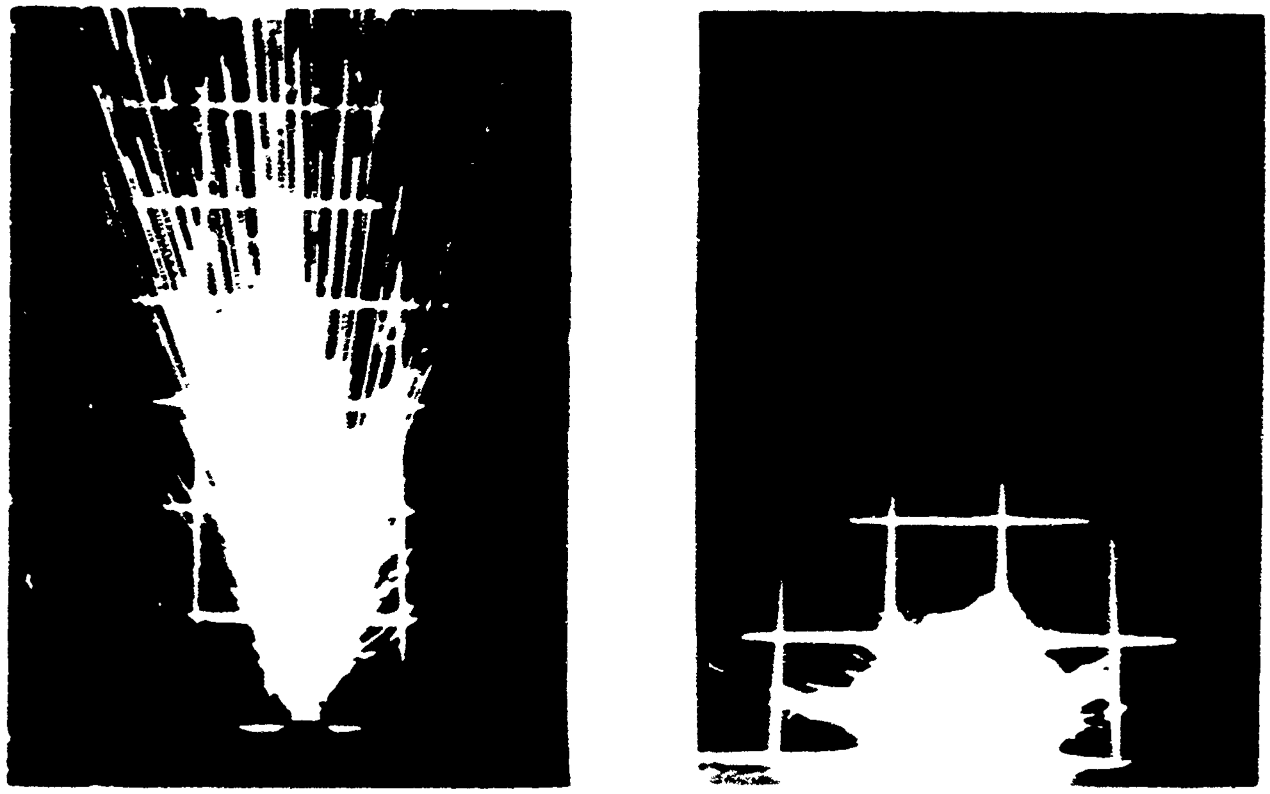


FIGURE 1. CUTAWAY VIEW OF GAS GENERATOR



UNIDYNAMICS SEALED MATCH

COMMERCIALLY AVAILABLE MATCH

FIGURE 2. COMPARISON OF FLASH OUTPUT OF UMC SEALED MATCH AND COMMERCIALLY AVAILABLE MATCH.

unburned particles will not be introduced into the electrolyte and of maintaining sufficient pressure in the gas generator to insure stable burning of the propellant. The base-end ignition system, together with the propellant grain trap and an efficient ignition powder, assures greater reliability in obtaining reproducible propellant ignition and combustion.

1.4.1.2 The ignition powder utilized in this design is a mixture of 39.1 percent zirconium, 47.8 percent barium chromate, and 13.1 percent borosilicate glass. This mixture is an easily ignited, fast burning, high calorific output material with the glass constituent providing "hot particles" for deep penetration of the propellant.

1.4.2 Delay Match Design. The design of the electric matches used in the generators is based on the standard sealed matches developed by Unidynamics for gas generator ignition. Figure 3 shows a cutaway view of a sealed electric delay match. Each delay match has the following design features:

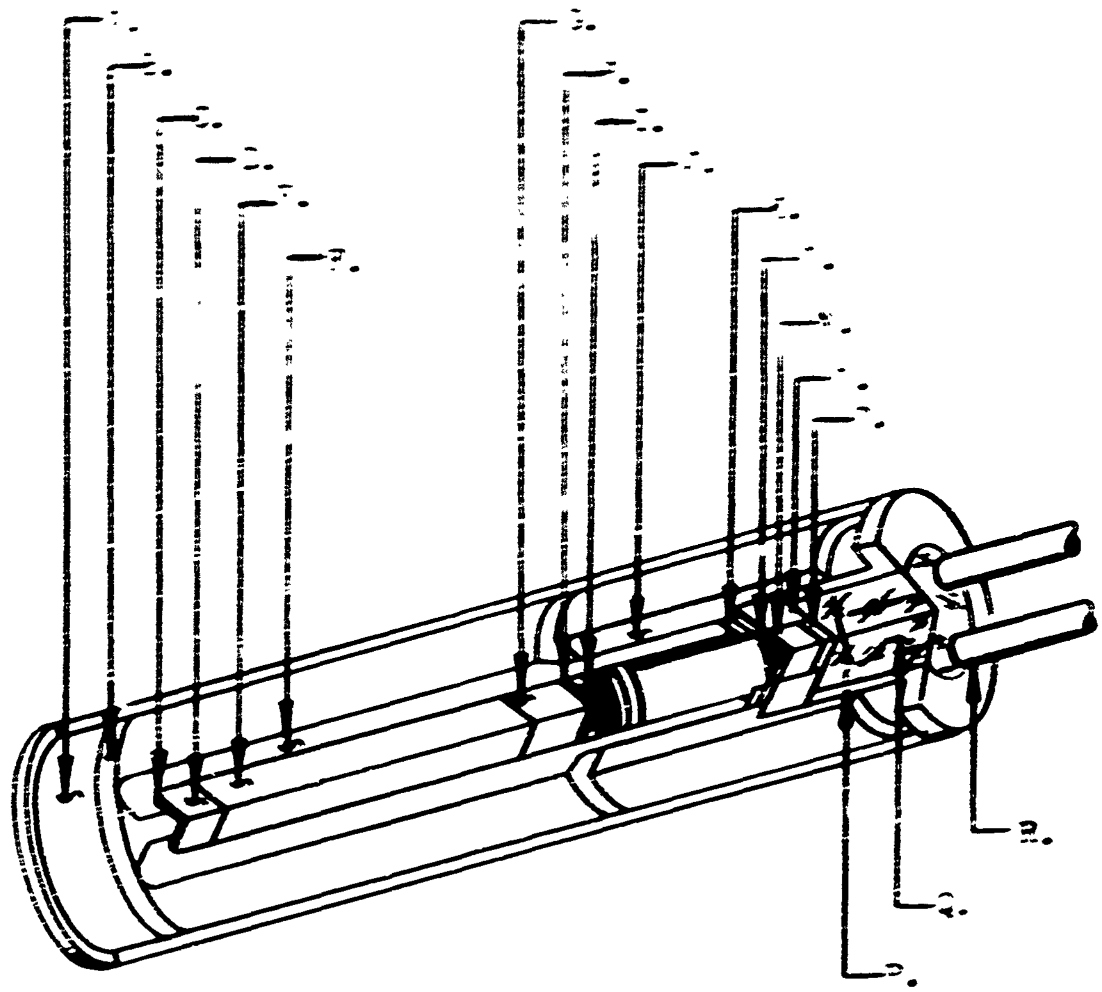
a. Bridgewire activation.

b. Pyrotechnic delay mix to yield 0.2- or 0.4-second delays.

c. Ignition material composed of basic lead styphnate and Flash Charge.

d. Resistance weld seal.

1.4.2.1 The bridgewire utilized for the delay match is a standard Tophet C bridgewire with a pressed charge of basic lead styphnate. The basic lead styphnate ignites upon activation of the bridgewire and transfers to a quantity of A-1A ignition powder (65 percent zirconium, 25 percent ferric oxide, and 10 percent Superfloss), which transfers the flame front to the delay column.



A. Flash Charge
B. Intermediate Charge
C. Wire Mesh Screen
D. Gasless Ignition Powder
E. Delay Composition
F. Delay Carrier
G. Gasless Ignition Powder
H. Wire Mesh Screen
I. Baffle
J. Charge Holder Retainer
K. Bearing Plate
L. Paper Disk
M. Gasless Ignition Powder
N. Charge Holder
O. Igniter Charge
P. Electrical Plug
Q. Glass Bead
R. Leads

FIGURE 3. SEALED ELECTRIC DELAY MATCH

1.4.2.2 The delay mix, composition (CBZ) is a mixture of 70 percent chromium, 20 percent barium chromate, and 10 percent potassium perchlorate, contained in a 0.1-inch diameter column, and ignited by A-1A ignition powder. A specific delay time can be obtained by a variation in the delay column lengths.

1.4.2.3 The Flash Charge of the sealed delay match is composed of basic lead styphnate and the zirconium-barium chromate-borosilicate glass Flash Charge previously discussed. The basic lead styphnate is ignited by heat transfer from the delay column, and ignites the Flash Charge composition in turn.

1.4.3 <u>Delay Match Testing</u>. Four series of tests were conducted on the delay matches to establish the following parameters:

a. The proper weld settings for accomplishing a hermetic seal;

b. The igniter charge weight required to obtain a satisfactory flash output;

c. The delay times specified for the matches.

1.4.3.1 The first test series consisted of seven 200-millisecond delay matches which were welded and tested to determine the proper weld settings for accomplishing a hermetic seal. Each match was loaded with an igniter-flash charge of six milligrams of basic lead styphnate and 50 milligrams of Flash Charge and with a quantity of delay mix which would theoretically yield a 200-millisecond delay. Various electrode designs and welder settings were used in an effort to produce a hermetic seal. The final electrode design and welder settings proved satisfactory and were used on

all subsequent units. After firing, the weld joints were visually examined to determine whether or not any deterioration occurred, and all welds remained intact.

1.4.3.2 The second test series consisted of 12 units (six of each delay time), which were stored at 300° F, then fired to determine the igniter charge weight required to obtain a satisfactory flash output after thermal conditioning at 300° F. Six units failed to rupture the bottom of the flash cup due to an insufficient quantity of basic lead styphnate igniter. Therefore, the charge weight of basic lead styphnate was increased from six milligrams to ten milligrams to insure rupturing of the delay match cup.

1.4.3.3 Concurrent with the above test series, a third series of 25 delay matches was subjected to thermal conditioning at various temperatures, then fired to determine the proper delay mix load required to obtain the specified delay times. Table III shows the conditioning temperature and the delay time results for each unit. The average delay time was 179 milliseconds for the 200-millisecond delay matches and 371 milliseconds for the 400-millisecond delay matches.* The delay times were proven to be reproducible. The low values for each delay match were attributed to an insufficient delay charge load.

*The erratic delays of 240 milliseconds and the 460 milliseconds respectively for the 200- and 400-millisecond delay matches stored at 300° F were eliminated from these averages since the delay cup of each barely ruptured. It was concluded that the cups expanded prior to rupturing and increased the apparent delay time. This problem is associated with the insufficient charge weight of basic lead styphnate discussed in the previous paragraph.

TABLE III

DELAY MATCH DATA

Unit No.	Conditioning Temp. (° F.)	Conditioning Time (Hrs)	Delay Time(2) (ms)
(200 ms Nominal Delay)			
1	-65	---	185
2	-65	---	170
3	-65	---	180
4	Ambient	---	185
5	212	---	190
6	(1)	---	215
7	300	72	170
8	300	120	240
9	300	120	170
10	300	168	165
(400 ms Nominal Delay)			
1	-65	---	375
2	-65	---	355
3	-65	---	370
4	Ambient	---	385
5	Ambient	---	365
6	212	---	370
7	212	---	345
8	212	---	385
9	(1)	---	340
10	(1)	---	335
11	(1)	---	350
12	(1)	---	340
13	300	72	355
14	300	120	345
15	300	168	460

(1) Thermal Shock - 5 cycles, each cycle consisting of 3 hours at -80° F followed immediately by 3 hours at 212° F.

(2) All units fired with a 6 V DC source across a 1.3 ohm bridge circuit.

1.4.3.4 A fourth test series of fourteen 200-millisecond and fourteen 400-millisecond delay matches was fabricated to test the effects of the improvements suggested from previous tests. The charge weight of the basic lead styphnate igniter was increased to ten milligrams and the delay column heights were also lengthened. At the request of the Signal Corps, all match test firings were conducted at -65° F. Six each of the 200- and 400-millisecond delay matches were stored for five to seven days at 300° F prior to conditioning at -65° F and firing. The results of the testing were as follows:

a. All 200-millisecond delay matches functioned properly and with reproducible results as shown in Table IV. However, the long delay times indicated that the delay charge weight was too great and required a reduction in thedelay column height to obtain the specified 200-millisecond delay.

b. The test results of the 400-millisecond delay matches showed that the output charge was being ignited by the delay charge in only 50 percent of the units. Post-mortem analysis revealed that the delay charge did not sustain burning. An engineering evaluation determined that either the A-1A delay charge igniter did not provide sufficient heat to ignite the delay column or the delay column diameter (0.082 inch) was too small.

1.4.3.5 A test series consisting of fifteen 400-millisecond delay sealed matches was fabricated and loaded in three groups, and testing was conducted to eliminate the causes for failure in the previous

TABLE IV

200-MILLISECOND DELAY MATCH DATA

All units tested at -65° F after four hours storage.

Unit No.	CONDITIONING Temp. (° F)	Time (Hrs.)	Delay Time (1) (ms)
1	300	120	243.5
2	300	120	249.8
3	300	120	240.1
4	300	120	237.6
5	300	168	244.5
6	300	168	240.3
7	Ambient	---	240.4
8	Ambient	---	240.3
9	Ambient	---	242.6
10	Ambient	---	248.3
11	Ambient	---	228.3
12	Ambient	---	229.6
13	Ambient	---	232.9
14	Ambient	---	229.8
AVERAGE			239.1
MAXIMUM			249.8
MINIMUM			228.3

(1) All units fired with a 6 V DC source across a 1.3-ohm bridge circuit.

test series. All test firings were conducted at -65° F.

a. Five units were fabricated with a 0.082-inch diameter delay column and loaded with 20 milligrams of 20/80 boron-calcium chromate ($B/CaCrO_4$) as the delay column igniter. The purpose of this group was to determine whether or not a delay ignition material with a higher calorific output than A-1A would sufficiently pre-heat the delay column and allow it to burn for 400 milliseconds. The advantage of this design would be the use of standard in-stock components and loading tools. All units in this group failed to transfer burning from the delay column to the output flash charge.

b. Ten units were fabricated with a 0.1-inch diameter delay column. Five were loaded with 20 milligrams of boron-calcium chromate as the delay mix igniter, and five were loaded with 20 milligrams of A-1A as the delay mix igniter. The purpose of these two groups was to determine whether or not the delay column would burn successfully in a 0.1-inch diameter delay column using either of the two igniter materials. All units in these two groups transferred burning from the delay column to the output flash charge. Figure 3 illustrates the orientation of components in the final design of the delay match.

1.4.4 Test Fixture. Prior to conducting the developmental testing, a test fixture was designed through a joint effort by the Signal Corps and Unidynamics. The purpose of the test fixture was to simulate the conditions of the gas generator installed in a battery and to measure output pressure and time-to-peak pressure of the gas generator and propellant.

1.4.4.1 The basic design of the test fixture is shown in Figure 4. This design features four burst disks which burst when a sufficient gas pressure is attained, allowing the gas to enter the upper chamber, which has a volume equal to the volume of electrolyte in an actual battery. As the pressure builds up in the upper chamber, the gas bleeds through exhaust ports into another chamber within fixed volume. The total volume of the two chambers is equal to the volume of gas produced by the gas generator. Thus, when the gas cools to ambient temperature, the pressure in both chambers should be one atmosphere. The test fixture eliminates the use of an electrolyte, but includes exhaust ports to simulate the back pressures encountered in the actual battery-activation system.

1.4.4.2 Testing in the test fixture showed that it leaked at the welded joint which secured the exhaust plate. As a result, the welded joint was replaced with "O" rings around both edges of the exhaust plate. The improved test fixture was tested for leakage by filling the lower chamber with water and pressurizing the upper chamber with air at 150 psi. No leaks were detected.

1.4.4.3 A series of standard 950 cc gas generators was tested to establish and characterize the test fixture pressure-versus-time data. N-5 propellant was used for this test series to provide a standard for comparison with the Unidynamics-developed propellant formulations. The testing was conducted at ambient temperature, and ignition was provided by a six-volt D.C. source. Table V shows the results of this testing. It was concluded that an average peak pressure of

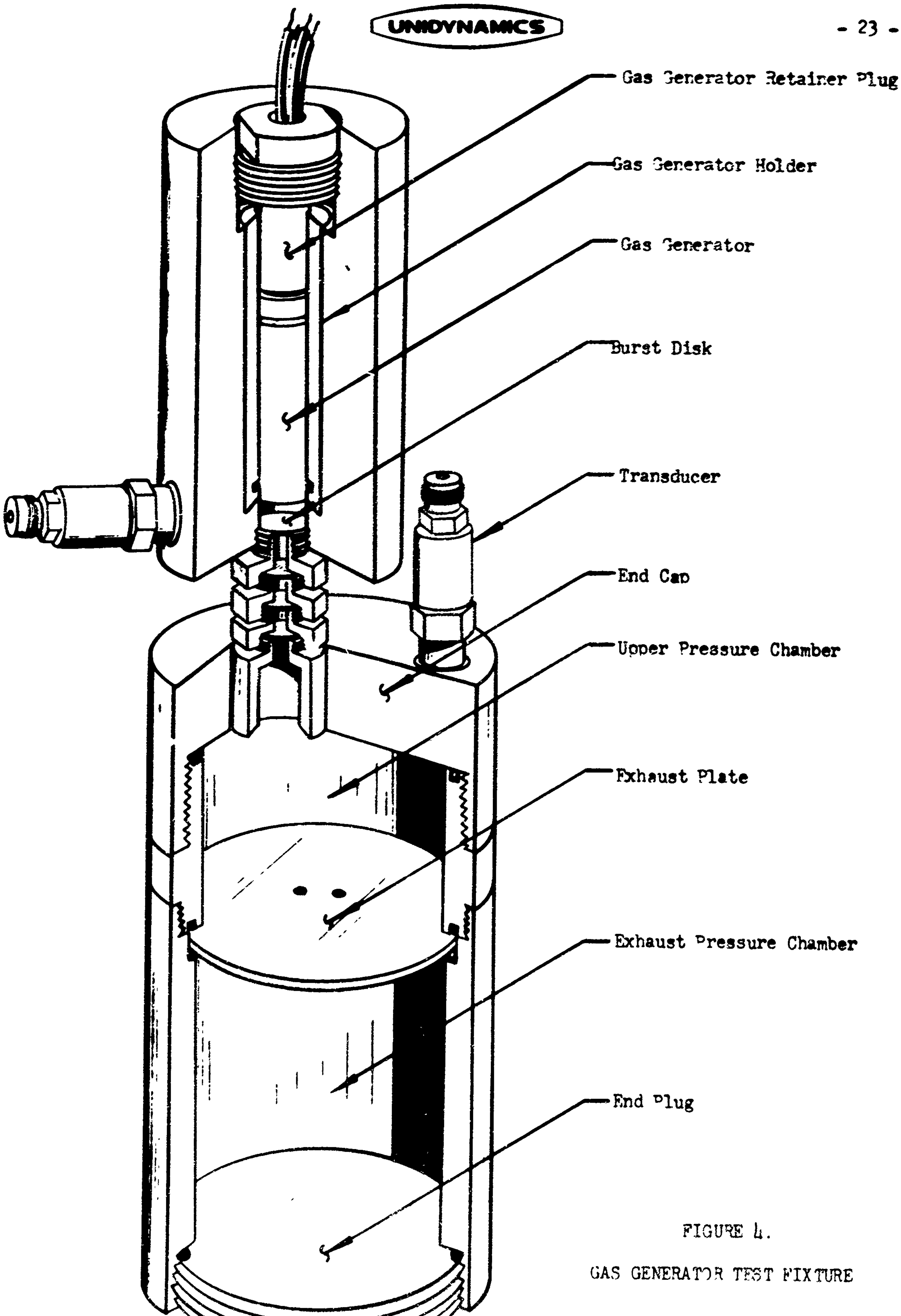


FIGURE 4.

GAS GENERATOR TEST FIXTURE

TABLE V

PRESSURE-VS-TIME FOR TEST FIXTURE EVALUATION

USING STANDARD GAS GENERATOR

Unit No.	Ignition Time (4) (μsec.)	Peak Pressure Chamber I (psi)	Time-to-Peak Chamber I (ms)	Peak Pressure Chamber II (psi)	Time-to-Peak Chamber II (ms)
1	300	(1)	(1)	50(2)	1600
2	340	1140	33	140	800
3	300	1120	82	95	800
4	500	1190	34	110	950
5	400	1200	29	110	800
6	300	1230	27	130	750
7	220	1300	28	(1)	(1)
8	(1)	1330	26	(3)	(3)
9	760	1175	22	70	1100
10.	780	870	22	140	750
Average	433	1173	34	101	969

(1) Scope did not trigger
(2) Test Fixture leaked
(3) Wrong sweep speed on scope
(4). All units fired with a 6 V DC source across a 1.3 ohm bridge circuit.

113 psi and an average time-to-peak of 850 milliseconds is required to duplicate the standard gas generators in the test fixture.

1.5 Development Testing. Unidynamics conducted developmental testing on the propellant formulations and gas generators developed under this contract in the following three areas: (1) gas output of the propellants; (2) thermal stability of the propellants; and (3) pressure-versus-time characteristics of the propellants when loaded into the gas generators. N-5 propellant was also subjected to these tests to provide a comparison with standard propellants currently being used for battery activation application. In addition, this same testing was performed on a commercially available propellant, B. F. Goodrich's C-501, to compare its thermal and output characteristics with the Unidynamics-developed propellants.

1.5.1 Gas Output Testing. Gas output tests were conducted to determine the volume of gas produced by each propellant measured in cubic centimeters-per-gram of propellant. The tests were conducted using the procedure given in Appendix A.

1.5.1.1 The first test series consisted of the two propellant formulations, N-1801 MOD A and N-1825, which yielded satisfactory results in the preliminary thermal stability testing, and N-5 propellant, included to provide a basis for comparison with standard propellants. The results of this test series, shown in Table VI, demonstrated that either N-1801 MOD A or N-1825 propellant formulation can be utilized in battery activation gas generator applications.

TABLE VI

GAS OUTPUT OF N-5, N-1801 MOD A, AND N-1825

Sample Number	N-5 Gas Output (cc/gm)	N-1801 MOD A Gas Output (cc/gm)	N-1825 Gas Output (cc/gm)
1	627	673	546
2	658	729	535
3	652	728	541
AVERAGE	646	710	541

1.5.1.2 A second series of gas output testing was conducted on three formulations based on N-1825 propellant. These formulations were designated N-1825A, N-1825B, and N-1825C (cf. p. 51). The gas output of these formulations closely approximated the 646 cubic centimeters-per-gram gas output of standard N-5 propellant. The results of this testing are shown in Table VII.

TABLE VII

GAS OUTPUT OF N-1825A, N-1825B, AND N-1825C

Sample Number	N-1825A Gas Output (co/gm)	N-1825B Gas Output (cc/gm)	N-1825C Gas Output (cc/gm)
1	641	605	662
2	633	628	658
3	647	617	662
AVERAGE	640	617	661

1.5.1.3 A third series of gas output testing was conducted to determine the effect of varying the percentage composition of the ammonium perchlorate oxidizer and guanidine picrate additive by plus or minus one percent. The formulations in this test series were N-1825D and N-1825E, two variations on N-1825B and differing only in a plus or minus one percent of oxidizer and additive, as well as N-1825B-3, which was a different batch prepared using the same formulation as N-1825B. The results indicated little effect from the ingredient variation and demonstrated that all three formulations have gas output characteristics similar to standard N-5 propellant. Table VIII shows the results of this test series.

TABLE VIII

GAS OUTPUT OF N-1825B, N-1825D, AND N-1825E

Sample Number	N-1825B Gas Output (cc/gm)	N-1825D Gas Output (cc/gm)	N-1825E Gas Output (cc/gm)
1	617	638	612
2	601	632	622
3	617	633	610
AVERAGE	612	634	615

1.5.2 Thermal Stability Testing. Thermal stability testing was conducted to determine: (1) the pressure of gases evolved during elevated temperature storage for seven days; (2) the weight loss incurred during elevated temperature storage for seven days in sealed units; and (3) the changes in physical characteristics after elevated

temperature storage for seven days. After the initial testing, the pressure gages were rendered inoperative due to overexposure to the extreme environmental conditions. Therefore, no effort was made to compare data on the pressure of the gases evolved in any series of thermal stability testing. Testing was conducted in accordance with the procedure given in Appendix B.

1.5.2.1 The first series of thermal stability testing was conducted using the N-1801 MOD A and N-1825 formulations which proved satisfactory in the preliminary thermal stability testing. Concurrently, N-5 propellant was tested to provide a basis for comparing the thermal stability characteristics of the Unidynamics-developed formulations with a standard propellant. The results of this test series demonstrated that the N-1825 propellant formulation lost considerably less weight than either N-5 or N-1801 MOD A. The test results are shown in Table IX.

TABLE IX

THERMAL STABILITY OF N-5, N-1801 MOD A AND N-1825

(300° F Storage for 168 Hours)

Sample Number	N-5 Weight Loss(1) (%)	N-1801 MOD A Weight Loss (%)	N-1825 Weight Loss (%)
1	3.37	16.86	0.48
2	3.57	18.04	0.53
AVERAGE	3.47	17.45	0.51

(1) Temperature storage limited to 200° F.

1.5.2.2 In conjunction with the propellant thermal stability tests, tests were conducted on milled, ground, and unground ammonium perchlorate to determine their individual thermal stability. These tests were conducted by storing samples of the ammonium perchlorate in open containers in 300° F environment for 168 hours and recording percent weight loss daily. Figure 5 shows the results of this testing. From ·s testing it was concluded that the use of ground ammonium perchlorate (particle size - 10 ± 5 microns) would improve the thermal stability of the propellants. Consequently all propellant formulations subsequent to N-1825A utilized ground ammonium perchlorate. Similar testing was conducted on propellants N-1825A, B, and C. The results of this testing are shown in Figure 6.

1.5.2.3 The second propellant thermal stability test series consisted of three variations of the N-1825 propellant formulation, N-1825A, N-1825B, and N-1825C. The results of this test series demonstrated that either N-1825A or N-1825B has sufficient thermal stability to withstand conditioning at 300° F for extended periods without deleterious effects. The results of this test series are shown in Table X.

TABLE X
THERMAL STABILITY OF N-1825A, N-1825B-1, and N-1825C
(300° F Storage for 168 hours)

Sample Number	N-1825A Weight Loss (%)	N-1825B-1 Weight Loss (%)	N-1825C[1] Weight Loss (%)
1	0.15	0.17	6.35
2	0.15	0.19	0.02
AVERAGE	0.15	0.18	----

(1) Variation attributed to weighing errors. No retest was conducted since this formulation did not perform satisfactorily in subsequent pressure-versus-time testing and was discarded as a possible candidate.

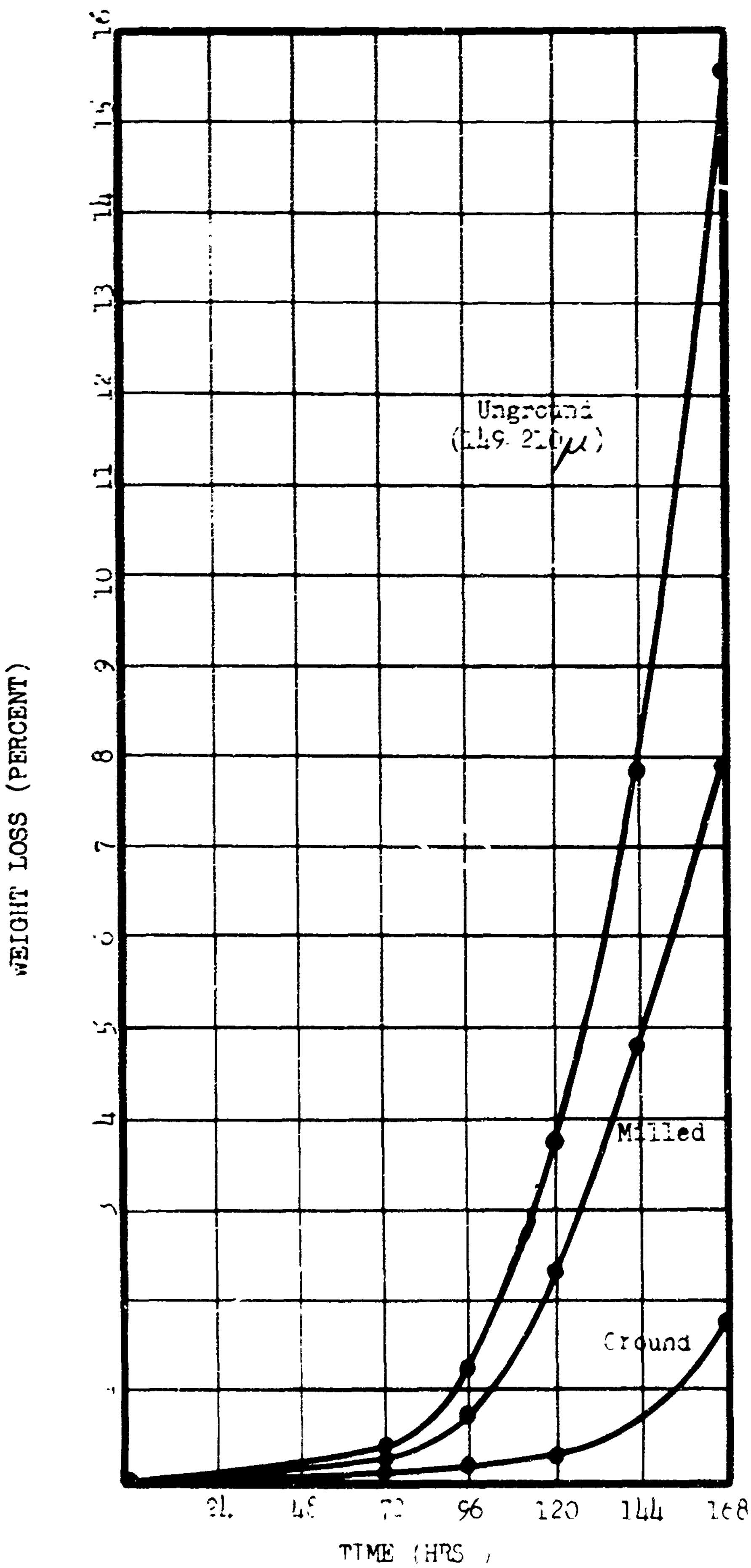


FIGURE 5. TIME-VS -WEIGHT LOSS FOR AMMONIUM PERCHLORATE
(300° F STORAGE-OPEN CONTAINERS)

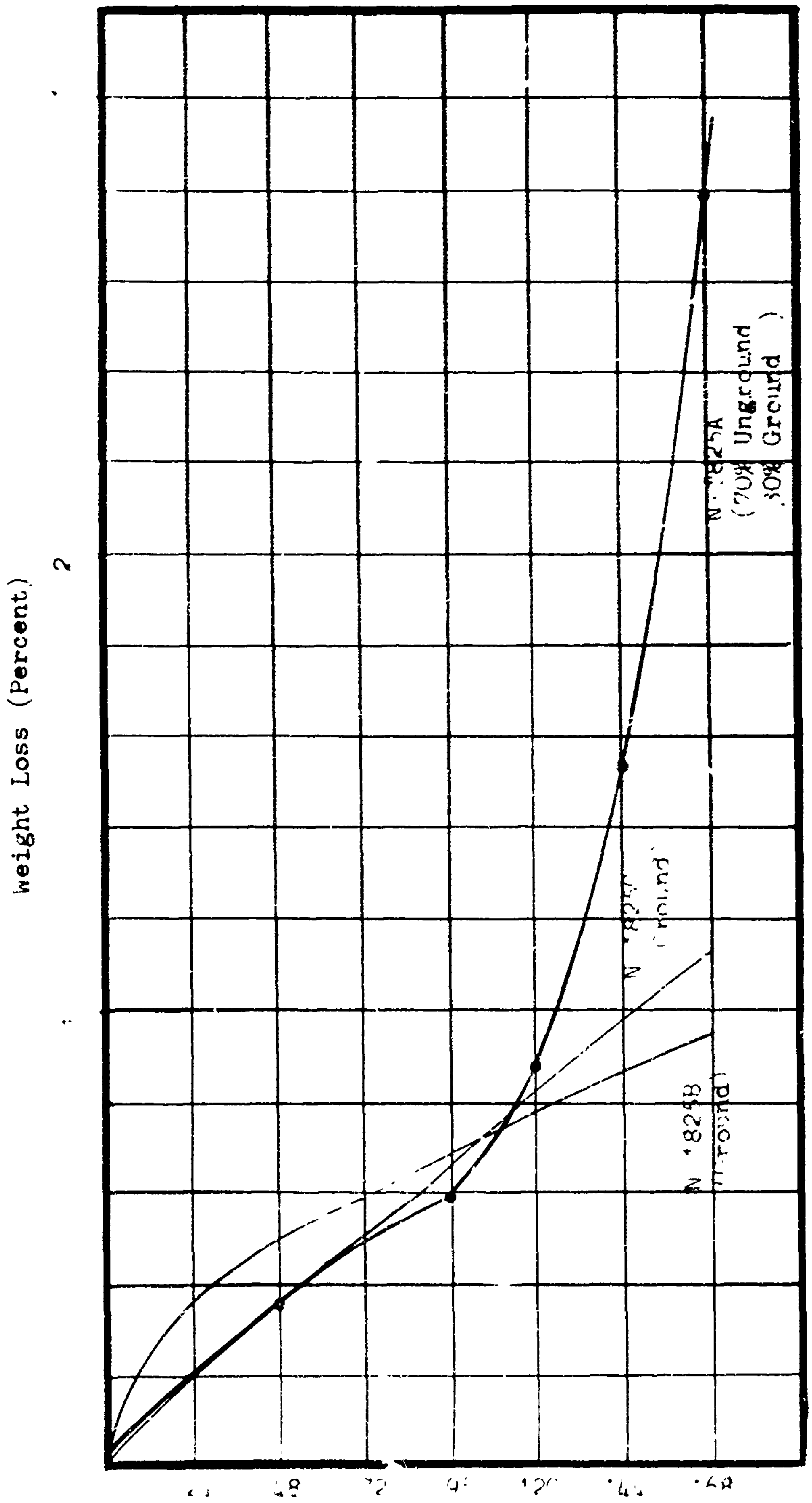


FIGURE 6 TIME-VERSUS WEIGHT LOSS
FOR PROPELLANTS N 1825A, B, AND C
[illegible] IN CONTAINERS)

1.5.2.4 The third group of propellant formulations tested for thermal stability were the N-1825 formulation and two variations, N-1825D and N-1825E, which differed from N-1825B by a variation in content of ammonium perchlorate oxidizer and guanidine picrate additive by plus or minus one percent. The results are shown in Table XI and demonstrate that the one percent variation in oxidiser and additive had no appreciable effect on the weight loss of either formulation.

TABLE XI

THERMAL STABILITY OF N-1825B-3, N-1825D AND N-1825E

Sample Number	N-1825B-3 Weight Loss (%)	N-1825D Weight Loss (%)	N-1825E Weight Loss (%)
1	0.36	0.40	0.37
2	0.40	(1)	(1)
AVERAGE	0.38	---	---

(1) One sample tested.

1.5.3 Initial Pressure-Versus-Time Testing. Pressure-versus-time testing was conducted to determine: (1) the effect of temperature variation on peak pressure, (2) time-to-peak pressure, and (3) ignition time. This testing required the use of the test fixture previously qualified. The gas generators used for the testing were 950 cc models, ignited by one Unidynamics instantaneous sealed match.

1.5.3.1 The first series of initial pressure-versus-time tests were conducted using 66 gas generators, one-third containing N-5 propellant, one-third containing formulation N-1801 MOD A, and one-third containing

formulation N-1825. The ignition material used was standard 666 composition (equal parts by weight of silicon, lead dioxide, cuprous oxide). Table XII shows the variation of the three propellant compositions over the temperature range and Tables XIII, XIV, and XV present the results of the testing.

TABLE XII

PERCENT DEVIATION FROM MEAN

Composition	Temperature Range	Peak Pressure (%)	Time-to-Peak Pressure (%)
N-5	-65 to 200° F	33.7	39.0
N-1801 MOD A(1)	-65 to 300° F	16.3	22.6
N-1825	-65 to 300° F	30.4	14.1

(1) Results do not include 300° F temperature storage.

1.5.3.2 The following is a discussion of the pressure-versus-time test results:

a. Observations of the units during the testing indicated that all units containing compositions N-5 and N-1825 functioned normally, while the units containing composition N-1801 MOD A functioned properly except for those stored at 300° F.

b. The two units containing N-1801 MOD A, which were stored for 72 hours at 300° F, blew out the base plugs. One unit was fired after 120 hours at 300° F with the base plug physically contained, but the leadwires were blown from this unit, thus allowing leakage. During each of these tests, the pressure ahead of the

TABLE XIII

PRESSURE-VS-TIME DATA FOR PROPELLANT N-5

Unit No.	Storage Temp. (° F)	Storage Time (Hrs.)	Ignition Time (6) (μ sec.)	Peak Pressure Chamber I (psi)	Time-To-Peak Chamber I (ms)	Peak Pressure Chamber II (psi)	Time-To-Peak Chamber II (ms)
1.	Ambient	-	150	1130	48	170	625
2.	Ambient	-	120	1351	49	- (1)	- (1)
3.	Ambient	-	170	1020	51	170	730
4.	Ambient	-	100	- (2)	- (2)	200	600
5.	-65	4	150	1200	56	160	710
6.	-65	4	150	- (2)	- (2)	140	720
7.	-65	4	140	810	165	200	680
8.	-65	4	100	900	50	200	640
9.	212	4	120	1180	35	- (3)	- (3)
10.	212	4	120	480	41	195	590
11.	212	4	100	900	34	230	480
12.	212	4	100	690	44	300	460
13.	TS (4)	30	90	- (5)	- (5)	205	560
14.	TS (4)	30	100	1200	33	220	460
15.	TS (4)	30	100	1170	72	260	460
16.	TS (4)	30	100	1290	31	230	420
17.	200	72	125	1080	27	220	480
18.	200	72	125	600	27	200	460
19.	200	120	120	1140	70	290	340
20.	200	120	150	1020	47	270	420
21.	200	168	40	900	35	250	460
22.	200	168	60	- (5)	0 (5)	370	320
AVERAGES				1003	51	224	531

(1) Camera shutter not opened
(2) Scope did not trigger
(3) Defective Film
(4) Thermal Shock - 5 cycles, each cycle consisting of 3 hours at -80° F followed immediately by 3 hours at 212° F.
(5) Rupture diaphrams apparently ruptured by hot particle rather than pressure rise.
(6) All units fired with a 6 V DC source across a 1.3 ohm bridge circuit.

TABLE XIV

PRESSURE-VS-TIME DATA FOR PROPELLANT N-1801 MOD A

Unit No.	Storage Temp. (° F)	Storage Time (Hrs.)	Ignition Time (8) (μsec.)	Peak Pressure Chamber I (psi)	Time-To-Peak Chamber I (ms)	Peak Pressure Chamber II (psi)	Time-To-Peak Chamber II (ms)
1.	Ambient	-	100	- (1)	- (1)	360	360
2.	Ambient	-	125	750	18	500	350
3.	Ambient	-	100	- (2)	- (2)	405	325
4.	Ambient	-	150	800	20	- (3)	- (3)
5.	-65	4	120	930	72	420	380
6.	-65	4	120	1200	27	390	380
7.	-65	4	80	900	25	380	340
8.	-65	4	80	900	20	400	360
9.	212	4	120	960	19	430	320
10.	212	4	120	1200	64	370	360
11.	212	4	40	540	20	460	240
12.	212	4	60	510	28	410	320
13.	TS (4)	30	85	1500	20	440	320
14.	TS (4)	30	120	960	24	370	380
15.	TS (4)	30	40	960	27	420	360
16.	TS (4)	30	110	960	21	430	300
17.	300	72	120	1800+	3	- (5)	- (5)
18.	300	72	100	1800+	3	- (5)	- (5)
19.	300	120	120	3000+	9	- (6)	- (6)
20.	300	120	-	-	-	- (7)	- (7)
21.	300	168	-	-	-	- (7)	- (7)
22.	300	168	-	-	-	- (7)	- (7)
AVERAGES				1157	25	412	340

(1) Intensity was too low
(2) Scope triggered late
(3) Wrong vertical sensitivity on scope
(4) Thermal shock - 5 cycles, each cycle consisting of 3 hours at -80° F followed immediately by 3 hours at 212° F.
(5) Base plugs blew out
(6) Leadwires were blown out of base plug
(7) Not fired because of anticipated similar results to Units 17, 18, and 19.
(8) All units fired with a 6 V DC source across a 1.3 ohm bridge circuit.

TABLE XV

TABLE XV

PRESSURE-VS-TIME DATA FOR PROPELLANT N-1825

Unit No.	Storage Temp. (° F)	Storage Time (Hrs.)	Ignition Time (4) (μ sec.)	Peak Pressure Chamber I (psi)	Time-To-Peak Chamber I (ms)	Peak Pressure Chamber II (psi)	Time-To-Peak Chamber II (ms)
1.	Ambient	-	110	1080	33	- (1)	- (1)
2.	Ambient	-	110	1110	39	200	800
3.	Ambient	-	100	900	24	160	850
4.	Ambient	-	100	930	27	230	800
5.	-65	4	80	900	85	270	760
6.	-65	4	120	870	46	200	840
7.	-65	4	120	990	80	240	760
8.	-65	4	80	900	41	230	800
9.	212	4	120	900	31	290	720
10.	212	4	120	870	24	280	700
11.	212	4	80	1080	20	290	600
12.	212	4	120	920	68	300	660
13.	TS (2)	30	120	990	72	240	700
14.	TS (2)	30	100	1020	30	280	700
15.	TS (2)	30	120	1080	23	280	640
16.	TS (2)	30	120	900	34	260	700
17.	300	72	80	1380	- (3)	200	640
18.	300	72	100	900	45	230	800
19.	300	120	120	960	35	260	640
20.	300	120	90	1140	77	250	600
21.	300	168	120	930	39	240	740
22.	300	168	100	1320	37	250	640
AVERAGES				1003	43	246	719

(1) Defective film
(2) Thermal Shock - 5 cycles, each cycle consisting of 3 hours at -80° F followed immediately by 3 hours at 212° F.
(3) Electronic counter did not stop
(4) All units fired with a 6 V DC source across a 1.3 ohm bridge circuit.

burst diaphragms was in excess of 3,500 psi. Consequently, the three remaining gas generators which had been stored at 300° F were not fired because the test fixture was not designed to withstand such high pressures.

c. In summary, the pressure-versus-time results for N-5, N-1801 MOD A, and N-1825 show that:

(1) Composition N-1825 gives more reproducible results with respect to pressure-versus-time than composition N-5;

(2) Composition N-1801 MOD A is unsuitable for 300° F applications;

(3) Time-to-peak pressure is an average 719 milliseconds for N-1825 compared with an average 531 milliseconds for N-5.

1.5.3.3 The second series of initial pressure-versus-time testing was conducted to determine: (1) whether or not the time-to-peak pressure of formulation N-1825 could be reduced to a value similar to that of N-5 by reducing the average oxidizer particle size, and (2) the effect of varying the percentages of the ammonium perchlorate oxidizer and the guanidine picrate additive. Three 5000-gram batches of propellant were prepared, and the percentage composition of each is given in Table XVI.

TABLE XVI

PERCENTAGE COMPOSITION OF N-1825-1, N-1825-2, and N-1825-3

Ingredient	N-1825-1 (% Composition)	N-1825-2 (% Composition)	N-1825-3 (% Composition)
Ammonium Perchlorate, Unground (Note)	33.95	40.95	26.95
Ammonium Perchlorate, Ground (10-20 micron size)	14.55	17.55	11.55
Hycar 1000 x 103	15.00	15.00	15.00
Guanidine Picrate	36.00	26.00	46.00
Carbon Black	0.50	0.50	0.50

Note: Subsequent testing proved that ground ammonium perchlorate is more stable than unground (cf. paragraph 1.5.2.2, p. 29). However, these formulations were prepared before the thermal stability test results were known.

1.5.3.4 Eight gas generators were loaded from each of three batches of propellant, using standard 666 ignition material and propellant grains with the same configuration as those previously tested. Four of the eight units from each propellant batch were test fired at ambient conditions in the test fixture, and the remaining 12 units were stored at 300° F for 168 hours and then fired in the test fixture. The results are shown in Tables XVII, XVIII, and XIX, and discussed in the following paragraphs:

a. The relatively large percentage weight loss during thermal stability testing demonstrated by these formulations (1.6-4.1 percent) and the erratic results from the test firings shown in Tables XVII, XVIII, and XIX were attributed to a change in

TABLE XVII

PRESSURE-VS-TIME DATA FOR PROPELLANT N-1825-1(1)

Unit No.	Propellant Weight (gms)	Storage Temp. (° F)	Storage Time (Hrs.)	Ignition Time (μsec.)	Peak Pressure Chamber I (psi)	Time-To-Peak Chamber I (ms)	Peak Pressure Chamber II (psi)	Time-To-Peak Chamber II (ms)
1.	2.4355	Ambient	---	200	450	54	180	840
2.	2.4495	Ambient	---	275	700	44	200	1100
3.	2.4355	Ambient	---	160	700	41	260	680
4.	2.4270	Ambient	---	250	480	43	260	1100
5.	2.4140	300	168	150	400	52	250	900
6.	2.4350	300	168	150	1800	62	230	480
7.	2.4275	300	168	200	1200	72	270	920
8.	2.4285	300	168	150	1110	56	300	840
AVERAGES					855	53	244	858
MAXIMUM					1800	72	300	1100
MINIMUM					400	41	180	480

(1) All units fired at ambient with a 6V DC source across a 1.3-ohm bridge circuit.

(2) Gas volume will not be determined until required generator sizes are fabricated.

TABLE XVIII

PRESSURE-VS-TIME DATA FOR [illegible] M-1825-2 (2)

Unit No.	Propellant Weight (gms)	Storage Temp. (° F)	Storage Time (Hrs.)	Ignition Time (µ sec.)	Peak Pressure Chamber I (psi)	Time-To-Peak Chamber I (ms)	Peak Pressure Chamber II (psi)	Time-To-Peak Chamber II (ms)
1.	2.5275	Ambient	---	325	840	39	330	600
2.	2.5435	Ambient	---	150	1200	30	440	480
3.	2.5595	Ambient	---	100	1600	42	350	500
4.	2.5055	Ambient	---	150	1050	39	300	600
5.	2.5350	300	168	175	2000	32	--(1)	--(1)
6.	2.5320	300	168	175	1450	43	700	120
7.	2.5695	300	168	175	1400	41	450	500
8.	2.4955	300	168	175	1400	38	400	780
AVERAGES					1368	38	424	526
MAXIMUM					2000	42	700	780
MINIMUM					840	30	300	120

(1) Camera malfunction.

(2) All units fired at ambient with a 6V DC source across a 1.3-ohm bridge circuit.

(3) Gas volume will not be determined until required generator sizes are fabricated.

UNIDYNAMICS

TABLE XIX

PRESSURE-VS-TIME DATA FOR PROPELLANT N-1825-3 (3)

Unit No.	Propellant Weight (gms)	STORAGE Temp. (°F)	STORAGE Time (hrs)	Ignition Time (μ sec.)	Peak Pressure Chamber I (psi)	Time-To-Peak Chamber I (ms)	Peak Pressure Chamber II (psi)	Time-To-Peak Chamber II (ms)
1.	2.3145	Ambient	---	200	1200	57	180	1100
2.	2.3095	Ambient	---	200	900	48	150	1280
3.	2.3235	Ambient	---	190	780	54	225	1200
4.	2.3130	Ambient	---	-(1)	-(1)	-(1)	180	1160
5.	2.3030	300	168	175	2100	58	280	700
6.	2.3060	300	168	125	2000	47	230	300
7.	2.3175	300	168	280	1440	68	170	1400
8.	2.3215	300	168	200	1150	65	-(2)	-(2)
	AVERAGES:			---	1367	57	202	1020
	MAXIMUM			---	2100	68	280	1400
	MINIMUM			---	780	47	150	300

(1) Scope Triggered Early

(2) Peak in Excess of 1800 ms.

(3) All units fired at ambient with 6V DC source across a 1.3-ohm bridge circuit.

the processing of the 5000-gram batches from previous preparations rather than to the propellant formulations. Several changes in the preparation procedure were made during the blending and drying of these batches. These changes include: (1) a scale-up of the mix size from 400 to 5000 grams; (2) the use of the five-gallon mixer in place of a one-quart mixer; (3) the use of new lots of Hycar 1000 x 103 rubber, ammonium perchlorate, and guanidine picrate; and, (4) the elimination of the drying and granulating portion of the mixing cycle since the aspirator could not produce a sufficient vacuum with the larger five-gallon mixer. In considering the relative importance of each of these changes, the conclusions reached were based primarily on past experience with the propellant type to which N-1825 belongs. In addition, the manner in which the properties of the propellant changed provide an indication of the causes of change. The performance changes which occurred were: (1) erratic pressure-vs-time functioning after 300° F storage for 168 hours, and (2) excessive weight loss in sealed pressure capsules after 300° F storage for 168 hours.

b. The scale-up of the mix size should have had no effect on the properties of the propellant. Past experience with extruded polybutadiene-acrylic acid has shown that this propellant type may be mixed in quantities from 1 to 50 pounds with reproducible results. As stated earlier, new lots of ammonium perchlorate, guanidine picrate, and Hycar 1000 x 103 were used. However, the ammonium perchlorate and Hycar 1000 x 103 were certified by the manufacturers to meet the standards of purity required.

by Unidynamics for this application. The guanidine picrate was prepared internally and conformed to Unidynamics Specifications.

c. The elimination of the drying and granulating portion of the mixing cycle did constitute a major change in the mixing procedure and was considered to be the source of the erratic results obtained with these propellant formulations. It is during the time that the solvent is drawn out of the propellant that much of the blending action occurs. As the solvent is removed, the binder becomes stiff, and considerable friction is produced by the action of the mixer blades. The shearing action which takes place is a very critical step in the incorporation of the solid ingredients into the rubber binder matrix. During this time the propellant is broken up into an extrudable granular form while the uniformity of the mixture is maintained. The elimination of this step in the mixing cycle was necessitated by the inability of the aspirator to produce a suitable vacuum. As a result, the propellant was removed from the mixer in a gummy form, cut into small cubes while still wet, and dried at 160° F. Through analysis of the product indicated that as the hexane evaporated from the propellant, the distribution of its solid constituents was altered, and, without further blending to maintain the proper distribution, the constituent distribution remained altered in the grains extruded for testing.

d. This series of tests confirmed the necessity of vacuum mixing for this type of propellant, since favorable time-to-peak pressures were not obtained for these batches which were not mixed under a vacuum. Therefore, all subsequent batches of N-1825 propellant were made in 400-gram batches to facilitate usage of equipment with vacuum milling capabilities.

1.5.4 Evaluation of C-501 Propellant. Based on the results of the previous testing and the availability of a commercial propellant which would theoretically meet the thermal stability and performance requirements for the Signal Corps gas generator, Unidynamics procured C-501 propellant from B. F. Goodrich Aero-Space and Defense Products for comparison with the Unidynamics-developed propellants as described in the following paragraphs.

1.5.4.1 A moisture analysis was conducted on propellant C-501 to determine the percentage of moisture contained in the propellant as received. The tests were conducted in duplicate using approximately 1-gram samples. The samples were weighed and then placed in a 160° oven for three hours; the loss in weight from this storage was recorded as moisture. (160° F was used in order to duplicate conditions previously utilized on other propellant tests). The results of the analysis showed the absorbed moisture to be 0.03 and zero percent by weight in two lots.

1.5.4.2 Rated gas output tests were conducted on propellant C-501 to determine the volume of gas produced in cubic centimeters. These tests were conducted in triplicate with approximately .3-gram

samples of the propellant in accordance with the procedure given in Appendix A. The results of this testing were as follows:

Sample No. 1 (cc/gm)	Sample No. 2 (cc/gm)	Sample No. 3 (cc/gm)	Average (cc/gm)
692	700	715	702.3

1.5.4.3 Thermal stability tests were conducted on propellant C-501 to determine:

1. the pressure of gases evolved during elevated temperature storage for 168 hours,
2. the amount of weight loss in sealed units during elevated temperature storage for 168 hours, and
3. the changes in the propellant's physical characteristics.

Testing was conducted in accordance with the procedure given in Appendix B. Two pressure capsules containing the C-501 propellant were placed in a 300° F oven and pressure readings were taken after one hour and then after each 24 hours for 168 hours. No pressure readings were obtained on the pressure gages. At the end of 168-hour storage at elevated temperature, the pressure capsules were post-mortemed to determine the physical changes of the propellant samples with respect to dimensions and weight. Table XX shows the physical parameters of the C-501 propellant samples before and after temperature storage. The percent weight loss of C-501 after 168 hours at 300° F was not greater than 1.2 percent, and indicated that C-501 propellant exhibits little tendency to decompose. Examination of the grains showed that

TABLE XX

PHYSICAL DATA ON C-501 PROPELLANT SAMPLES BEFORE AND AFTER 300° F STORAGE FOR 168 HOURS

	Capsule No. 1	Capsule No. 2
Grain Diameter Before (in.)	.375	.375
Grain Diameter After (in.)	.384	.389
Grain Length Before (in.)	2.019	2.024
Grain Length After (in.)	2.020	2.010
Weight Before (gms.)	5.3153	5.3152
Weight After (gms.)	5.3060	5.2515
Weight Loss (gms.)	.0093	.0637
Percent Weight Loss (%)	.18	1.2
Apparent Density (gms/cc)	1.67	1.66

the propellant retained some of its flexibility and was apparently not detrimentally affected physically.

1.5.4.4 Pressure-versus-time tests were conducted on C-501 propellant to determine the effect of conditioning temperature variation on peak-pressure, time-to-peak pressure, and ignition time. Twenty-two 950 cc gas generators, ignited by one Unidynamics instantaneous sealed match, were fabricated utilizing standard 666 composition as the ignition material. The units were tested in the test fixture and Table XXI shows the percent variation from the mean of the peak-pressure and time-to-peak pressure on propellant C-501. The test conditions and pressure-versus-time test results are presented in Table XXII. In addition, the results from previous testing with N-5 and N-1825 are included for comparison.

TABLE XXI

COMPARATIVE PERCENT VARIATION FROM MEAN FOR N-5, N-1825, AND C-501

Composition	Temperature Range	Peak Pressure (%)	Time-To-Peak Pressure (%)
N-5	-65 to 200° F	32	39
N-1825	-65 to 300° F	30	17
C-501	-65 to 300° F	29	22

1.5.4.5 Upon completion of the evaluation testing of C-501 propellant, the following conclusions were reached jointly by the Signal Corps and Unidynamics:

a. Propellant C-501 had performed satisfactorily in all testing to which it was subjected, but the exhaust gases contained

TABLE XXII

TABLE XXII

PRESSURE-VS-TIME DATA FOR PROPELLANT C-501

NOTE: All units fired with a 6 Volt DC source across a 1.3-ohm bridge circuit

Unit No.	Propellant Weight (gms)	STORAGE Temp. (°F)	STORAGE Time (hrs.)	Ignition Time (μsec.)	Peak Pressure Chamber I (psi)	Time-To-Peak Chamber I (ms)	Peak Pressure Chamber II (psi)	Time-To-Peak Chamber II (ms)
1.	2.2701	Ambient	---	---	500	19	320	320
2.	2.3136	Ambient	---	170	1125	8	400	360
3.	2.3955	Ambient	---	210	480	11	(2)	(2)
4.	2.3187	Ambient	---	140	580	12	490	360
5.	2.3484	-65	4	180	540	10	470	300
6.	2.4036	-65	4	175	420	11	500	280
7.	2.3280	-65	4	215	1385	22	440	330
8.	2.2884	-65	4	180	740	63	485	300
9.	2.3953	212	24	175	1380	25	390	320
10.	2.4205	212	24	150	1230	26	480	300
11.	2.3799	212	24	160	1020	81	580	300
12.	2.3626	212	24	150	1320	25	545	310
13.	2.4157	TS (1)	30	175	1440	83	550	360
14.	2.3479	TS (1)	30	180	1275	26	500	280
15.	2.3775	TS (1)	30	160	1200	92	500	330
16.	2.4335	TS (1)	30	225	1380	67	490	330
17.	2.3433	300	72	---	1140	10	420	335
18.	2.4000	300	72	190	880	13	360	420
19.	2.3825	300	120	190	1200	55	396	365
20.	2.4035	300	120	185	1260	48	405	420
21.	2.3864	300	168	170	1080	77	380	390
22.	2.3118	300	168	200	1290	103	420	440
	AVERAGES:			---	1029	40	453	326
	MAXIMUM			---	1440	103	580	440
	MINIMUM			---	420	8	320	280

(1) Thermal Shock - 5 cycles, each cycle consisting of 3 hours at -65° F followed immediately by 3 hours at 212° F.

(2) Scope Malfunction

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twice the amount of hydrochloric acid as N-1825 propellant.

b. Propellant C-501 is a cast propellant and cannot be furnished with center perforations

c. N-1825 is an extrudable propellant and can be furnished in any configuration for which a die can be made.

d. The basic N-1825 formulation could be stabilized, and better reproducibility could be obtained.

1.5.5 Final Pressure-Versus-Time Testing. Based on the above conclusions, a propellant study was initiated to formulate a propellant incorporating the basic N-1825 constituents that would have the following characteristics: (1) lot-to-lot reproducibility, (2) thermal stability at 300° F for 168 hours, and (3) a time-to-peak pressure less than 531 milliseconds.

1.5.5.1 The first pressure-versus-time test series of this study consisted of ten 950 cc gas generators loaded with one Unidynamics instantaneous sealed match, standard 666 ignition material, and a propellant formulation designated N-1825A.* Five units were tested after ambient storage, and five were tested after storage at 300° F for 168 hours. Table XXIII shows the results of this testing. The average time-to-peak pressure was 548 milliseconds with a range of plus 198 and minus 148 milliseconds. The percentage composition of N-1825A is shown in Table XXIV, and was formulated to reproduce the performance of batch N-1825-[illegible] previously tested.

*Although two matches are required in the end item to provide redundant ignition, only one match was utilized in this test series in the interest of economy. Should a failure to ignite have occurred, the match could have been replaced with minimum lost time.

TABLE XXIII

PRESSURE-VERSUS-TIME DATA

PROPELLANT N-1825A

Firing Temperature - Ambient

NOTE: All units fired with a 6 Volt DC source across a 1.3-ohm bridge circuit.

Unit No.	Storage Temp. (°F)	Storage Time (hrs.)	Peak Pressure Chamber II (psi)	Time-To-Peak Pressure (ms)
1	300	168	400	400
2	300	168	340	600
3	300	168	410	400
4	300	168	360	570
5	300	168	(1)	(1)
6	Ambient	---	330	750
7	Ambient	---	280	560
8	Ambient	---	300	610
9	Ambient	---	400	480
10	Ambient	---	400	560
AVERAGE			358	548
MAXIMUM			410	750
MINIMUM			280	400

(1) Bad Film

TABLE XXIV
PERCENTAGE COMPOSITION OF N-1825A

Ingredient	N-1825A (% Composition)
Ammonium Perchlorate, Unground (See Note, Table XVI, p. 38)	41.65
Ammonium Perchlorate, Ground (mean particle size of 13 microns)	17.85
Guanidine Picrate	25.00
Hycar 1000 x 103	15.00
Carbon Black	0.50

1.5.5.2 The second test series in the propellant study was conducted on propellant formulations N-1825B and N-1825C to determine which of the two exhibited a time-to-peak pressure similar to that of N-5. These two propellant formulations utilized the conclusions of the thermal stability testing of the ammonium perchlorate oxidizer and incorporated all ground ammonium perchlorate to provide greater thermal stability for the propellants. The percentage composition of the two propellants is shown in Table XXV, and differs only in the percent of ammonium perchlorate oxidizer and guanidine picrate additive.

TABLE XXV
PERCENT COMPOSITION OF N-1825B and N-1825C

Ingredient	N-1825B (% Composition)	N-1825C (% Composition)
Ammonium Perchlorate, Ground	56.5	59.5
Hycar 1000 x 103	16.0	16.0
Guanidine Picrate	27.0	24.0
Carbon Black	0.5	0.5
	100.0	100.0

1.5.5.3 Five units were loaded with each formulation, utilizing one Unidynamics instantaneous sealed match and standard 666 ignition material. All units were tested at ambient conditions in the test fixture. Tables XXVI and XXVII show the pressure-versus-time data for propellants N-1825B and N-1825C, and Table XXVIII shows a comparison of the pressure-versus-time results for propellants N-1825B, N-1825C, and standard N-5. An analysis of the data obtained from this series of testing led to the following conclusions:

a. N-1825B has burn time characteristics similar to those exhibited by N-5 propellant;

b. Delay problems in pressure buildup in Chamber II of the test fixture were prevalent and could be attributed to: (1) the 666 ignition material or (2) the rupturing of the burst disk which would allow the pressure to drop at a high rate to less than 100 psi.

1.5.5.4 As a result of the above conclusions, ignition tests were conducted to determine whether the large variation in time-to-peak pressure was the result of poor ignition by the 666 ignition material or the result of the sudden reduction in pressure when the burst disks ruptured. The first test series utilized N-1825B propellant and consisted of six units. The ignition material in the first three was a zirconium/barium chromate mixture incorporating ground glass. The second three units contained silicon/lead dioxide as the ignition material. These units were tested in the

TABLE XXVI

PRESSURE-VERSUS-TIME DATA

PROPELLANT N-1825B

Storage Temperature - Ambient
Firing Temperature - Ambient

Unit No.	Ignition Material	Peak Pressure Chamber II (psi)	Time-To-Peak Pressure (ms)
1	666*	350	380
2	666	370	470
3	666	300	520
4	666	360	450
5	666	390	600
AVERAGE		374	484
MAXIMUM		390	600
MINIMUM		300	380

*Equal parts of cuprous oxide, lead dioxide, and silicon.

NOTE: All units fired with a 6 V DC source across a 1.3-ohm bridge circuit.

TABLE XXVII

PRESSURE-VERSUS-TIME DATA

PROPELLANT N-1825C

Storage Temperature - Ambient
Firing Temperature - Ambient

Unit No.	Ignition Material	Peak Pressure Chamber II (psi)	Time-To-Peak Pressure (ms)
1.	666*	410	320
2.	666	260	350
3.	666	330	330
4.	666	420	270
5.	666	330	480
AVERAGE		350	350
MAXIMUM		420	480
MINIMUM		260	270

*Equal parts of cuprous oxide, lead dioxide, and silicon.

NOTE: All units fired with a 6 V DC source across a 1.3-ohm bridge circuit.

TABLE XXVIII

COMPARISON OF PRESSURE-VERSUS-TIME RESULTS FOR

PROPELLANTS N-1825B, N-1825C, AND N-5

Firing Temperature - Ambient

Item	N-1825B	N-1825C	N-5
Average Time-To-Peak (ms)	484	350	531
Maximum Time-To-Peak (ms)	600	480	730
Minimum Time-To-Peak (ms)	380	270	320
Average Peak Pressure (psi)	374	350	224
Maximum Peak Pressure (psi)	390	420	370
Minimum Peak Pressure (psi)	300	260	140

NOTE: All units fired with a 6 V DC source across a 1.3-ohm bridge circuit.

Signal Corps Test Fixture. The results of this testing are shown in Table XXIX. The pressure-versus-time traces on these tests show that the zirconium/glass/barium chromate mixture provided more uniform ignition characteristics, and also showed that the ignition material was not the entire cause of ignition delays. Subsequent to these tests, five additional units were loaded using N-1825B propellant with a zirconium/glass/barium chromate mixture as the ignition material. These units were tested in the Signal Corps Test Fixture with a nozzle between the gas generator and the first burst disk. The purpose of this nozzle was to maintain a pressure in the gas generator which would be sufficiently high to insure stable burning. The results of this testing as shown in Table XXX led to the following conclusions:

a. N-1825B propellant had reproducible burning characteristics;

b. N-1825B could be tailored to meet most Signal Corps requirements;

c. A nozzle would be required on the gas generator to maintain internal pressures sufficiently high to insure stable burning of the propellant grain.

1.5.5.5 A third series of pressure-versus-time testing was conducted using three additional propellant batches to determine: (1) manufacturing reproducibility of N-1825 and (2) manufacturing tolerances on percentage composition of oxidizer and coolant additive. The formulations were designated N-1825B-3, N-1825D, and N-1825E; Table XXXI shows the percentage compositions of the three batches.

TABLE XXIX

PRESSURE-VERSUS-TIME DATA

PROPELLANT N-1825B

Storage Temperature - Ambient
Firing Temperature - Ambient

Unit No.	Ignition Material	Peak Pressure Chamber II (psi)	Time-To-Peak Pressure (ms)
1	(1)	350	570
2	(1)	380	660
3	(1)	320	530
4	(2)	290	680
5	(2)	430	440
6	(2)	340	500
AVERAGE UNITS 1 TO 3		350	587
AVERAGE UNITS 4 - 5		353	540

(1) Zirconium 39.1%
Barium Chromate 47.8%
Borosilicate Glass 13.1%

(2) Silicon 15%
Lead Dioxide 85%

NOTE: All units fired with a 6 V DC source across a 1.3-ohm bridge circuit.

TABLE XXX

PRESSURE-VERSUS-TIME DATA

PROPELLANT N-1825B

Storage Temperature - Ambient
Firing Temperature - Ambient
One-tenth-inch diameter nozzle between gas generator and burst disk No. 1

Unit No.	Ignition Material	Peak Pressure Chamber II (psi)	Time-To-Peak Pressure (ms)
1	(2)	440	250
2	(2)	370	240
3	(2)	330	300
4	(2)	(1)	(1)
5	(2)	(1)	(1)
AVERAGE		380	263
MAXIMUM		440	300
MINIMUM		330	240

(1) Transducer orifice clogged

(2) Zirconium 39.1%
Barium Chromate 47.8%
Borosilicate Glass 13.1%

NOTE: All units fired with a 6 V DC source across a 1.3-ohm bridge circuit.

TABLE XXX

PRESSURE-VERSUS-TIME DATA

PROPELLANT N-1825B

Storage Temperature - Ambient
Firing Temperature - Ambient
One-tenth-inch diameter nozzle between gas generator and burst disk No. 1

Unit No.	Ignition Material	Peak Pressure Chamber II (psi)	Time-To-Peak Pressure (ms)
1	(2)	440	250
2	(2)	370	240
3	(2)	330	300
4	(2)	(1)	(1)
5	(2)	(1)	(1)
AVERAGE		380	263
MAXIMUM		440	300
MINIMUM		330	240

(1) Transducer orifice clogged

(2) Zirconium 39.1%
Barium Chromate 47.8%
Borosilicate Glass 13.1%

NOTE: All units fired with a 6 V DC source across a 1.3-ohm bridge circuit.

TABLE XXXI

PERCENTAGE COMPOSITION OF N-1825B-3, N-1825D, AND N-1825E

Ingredient	N-1825B-3(1) (% Composition)	N-1825D (% Composition)	N-1825E (% Composition)
Ammonium Perchlorate, Ground	56.5	57.5	55.5
Guanidine Picrate	27.0	26.0	28.0
Hycar 1000 x 1-3	16.0	16.0	16.0
Carbon Black	0.5	0.5	0.5
	100.0	100.0	100.0

(1) Identical formulation as N-1825B prepared previously.

1.5.5.6 Twelve units were loaded with the N-1825B-3 propellant, eight units loaded with N-1825D, and eight units loaded with N-1825E, All units utilized one Unidynamics instantaneous sealed match and the zirconium/glass/barium chromate mixture as the ignition material. The units were tested in the test fixture with a one-tenth-inch diameter nozzle between the gas generator and the first burst disk. The pressure-versus-time data obtained from firing the units is presented in Tables XXXII, XXXIII, and XXXIV. It was concluded from the results of this test series that:

a. N-1825B propellant yields batch-to-batch reproducibility;

b. variations of plus or minus one percent in either the oxidizer or the coolant additive has little effect on the pressure-versus-time characteristics.

1.6 Environmental Testing. Unidynamics conducted an extensive environmental test program on the gas generators and N-1825B propellant

TABLE XXXII

PRESSURE-VERSUS-TIME DATA

PROPELLANT N-1825B-3

One-tenth-inch nozzle between gas generator and burst disk No. 1
Ignition material: Zr, 39.1% - $BaCrO_4$, 47.8% - Borosilicate Glass, 13.1 %

Unit No.	STORAGE Temp. (°F)	Time (hrs.)	Peak Pressure Chamber II (psi)	Time-To-Peak Chamber II (ms)
1	Ambient	---	340	270
2	Ambient	---	325	310
3	Ambient	---	375	270
4	Ambient	---	325	270
5	Ambient	---	320	270
6	Ambient	---	390	280
7	300	168	360	220
8	300	168	350	230
9	300	168	350	240
10	300	168	380	260
11	Ambient	---	340	270
12	Ambient	---	330	250
AVERAGE			349	262
MAXIMUM			390	310
MINIMUM			320	220

NOTE: All units fired with a 6 V DC source across a 1.3-ohm bridge circuit.

TABLE XXXIII

PRESSURE-VERSUS-TIME DATA

PROPELLANT N-1825D

One-tenth-inch nozzle between gas generator and burst disk No. 1
Ignition material: Zr, 39.1% - $BaCrO_4$, 47.8% - Borosilicate Glass, 13.1%

Unit No.	STORAGE Temp. (°F)	Time (hrs.)	Peak Pressure Chamber II (psi)	Time-To-Peak Chamber II (ms)
1	300	168	460	260
2	300	168	450	210
3	300	168	380	210
4	300	168	330	290
5	Ambient	---	360	290
6	Ambient	---	350	230
7	Ambient	---	370	270
8	Ambient	---	350	290
AVERAGE			381	256
MAXIMUM			460	290
MINIMUM			330	210

NOTE: All units fired with a 6 V DC source across a 1.3-ohm bridge circuit.

TABLE XXXIV

PRESSURE-VERSUS-TIME DATA

PROPELLANT N-1825E

One-tenth-inch nozzle between gas generator and burst disk No. 1
Ignition material: Zr, 39.1% - $BaCrO_4$, 47.8% - Borosilicate Glass, 13.1 %

Unit No.	Storage Temp. (°F)	Storage Time (hrs.)	Peak Pressure Chamber II (psi)	Time-To-Peak Chamber II (ms)
1	300	168	380	290
2	300	168	370	240
3	300	168	380	280
4	300	168	380	220
5	Ambient	---	340	250
6	Ambient	---	350	260
7	Ambient	---	320	250
8	Ambient	---	390	230
AVERAGE			364	253
MAXIMUM			390	290
MINIMUM			320	220

NOTE: All units fired with a 6 V DC source across a 1.3-ohm bridge circuit.

developed under this contract to determine: (1) the advantage of either locating the sealed matches at the base plug or at the exhaust end of the gas generator, and (2) whether or not propellant N-1825B would withstand the environmental conditioning specified in Signal Corps Technical Requirement SCL-7564.

1.6.1 In the first environmental test series, 24 gas generators were fabricated which would theoretically produce 950 cc of gas. Twelve of these units utilized base plug ignition, while the remaining twelve units utilized exhaust end ignition. Each of these units contained two sealed matches, 300 milligrams of zirconium/barium chromate/ground glass ignition material, and a nozzle with three exhaust ports. The diameter of these ports resulted in approximately the same effective cross-sectional area as the single 0.1-inch diameter nozzle in the test fixture. The same cross-sectional area was utilized in an attempt to maintain the time-to-peak established during the propellant study.

1.6.1.1 The gas generators were conditioned under various environmental conditions and test fired in the Signal Corps Test Fixture. Table XXXV shows the environmental conditioning of each unit and the test results of each unit with exhaust end ignition. Table XXXVI shows the environmental conditioning and test firing results from the units utilizing base plug ignition. From the test results it is concluded that:

(1) Locating the sealed matches at the base plug end of the Gas Generator is relatively easier to manufacture than the exhaust

TABLE XXXV

950 CC GAS GENERATOR TEST DATA

Igniters: Two Unidynamics sealed matches located at exhaust.

Unit No.	Propellant Weight (gms)	Environmental Conditioning	Ignition Time (μsec.)	Peak Pressure Chamber II (psi)	Time-To-Peak Chamber II (ms)	Gas Volume Calculated (CC)	Resistance After Firing (K ohms) (1)	Resistance After Firing (K ohms) (2)
1	1.8990	(1)	230	170	200	1160	43	1,500
2	1.9100	(1)	250	290	180	1209	850	5
3	1.8930	(2)	240	220	650	1090	∞	22
4	1.9100	(2)(3)	250	240	840	1095	2	∞
5	1.9045	(2)(3)(4)	280	(8)	(8)	1045	130	70
6	1.9045	(2)(3)(4)(5)	250	190	570	1155	∞	9
7	1.9030	(2)(3)(4)(5)	240	210(9)	250(9)	(9)	(9)	30
8	1.8855	(2)(3)(4)(5)(6)	250	320	230	1170	∞	150
9	1.9145	(2)(3)(4)(5)(6)	190	230(9)	90(9)	(9)	(9)	(9)
10	1.9160	(2)(3)(4)(5)(6)	280	150(9)	550(9)	(9)	(9)	(9)
11	1.9100	(2)(3)(4)(5)(6)	240	(9)	(9)	(9)	(9)	(9)
12	1.9070	(2)(3)(4)(5)(6)(7)	245	190(9)	160(9)	(9)	(9)	(9)
AVERAGE:	1.9047		245	221	372	1132		
MAXIMUM:	1.9160		280	320	840	1209		
MINIMUM:	1.8845		190	150	90	1045		

(1) AMBIENT - No conditioning.
(2) 300° F storage for 168 hours.
(3) -80° F storage for 72 hours.
(4) Thermal shock - 5 cycles each cycle consisting of 3 hours at -80° F followed immediately by 3 hours at 212° F.
(5) Mechanical Shock - 250 g's impact once in each of the 2 major axis.
(6) Vibration - 5 cps to 50 cps at .4 inches double amplitude displacement - 50 cps to 2000 cps at 35 g's - cycling time 60 minutes per axes on 2 major axes.
(7) Match sensitivity - 50 milliampere pulse for one second on each of the two matches - time between pulses 5½ seconds.
(8) Peak off scale - excess of 900 ms.
(9) Leaked - leadwires blew out of base plug.
(10) All units fired with a 6 Volt DC source across a 1.3-ohm bridge circuit.

TABLE XXXVI

950 CC GAS GENERATOR TEST DATA

Igniters: Two Unidynamics sealed matches located at base plug.

Unit No.	Propellant Weight (gms)	Environmental Conditioning	Ignition Time (μ sec.)	Peak Pressure Chamber II (psi)	Time-To-Peak Chamber II (ms)	Gas Volume Calculated (CC)	Resistance After Firing (K ohms)	
1	1.9095	(1)	230	260	160	1150	300	130
2	1.9115	(1)	285	310	170	1090	140	∞
3	1.9160	(2)	240	190	570	1090	230	∞
4	1.9025	(2)(3)	220	280	410	1215	3,000	550
5	1.9065	(2)(3)(4)	(8)	360	170	1232	∞	∞
6	1.9135	(2)(3)(4)(5)	230	250	180	1150	∞	∞
7	1.8885	(2)(3)(4)(5)	250	240	260	1035	500	∞
8	1.8845	(2)(3)(4)(5)(6)	250	180	530	1100	1,500	∞
9	1.8890	(2)(3)(4)(5)(6)	240	230	250	1159	5,000	∞
10	1.8735	(2)(3)(4)(5)(6)	185	140	570	1161	4,000	∞
11	1.8760	(2)(3)(4)(5)(6)	175	230	400	1166	∞	290
12	1.9010	(2)(3)(4)(5)(6)(7)	180	320	190	1166	460	∞
AVERAGE:	1.8977		226	249	322	1143		
MAXIMUM:	1.9160		285	360	570	1232		
MINIMUM:	1.8735		175	140	160	1035		

(1) AMBIENT - No conditioning
(2) 300° F storage for 168 hours.
(3) -80° F storage for 72 hours.
(4) Thermal shock - 5 cycles each cycle consisting of 3 hours at -80° F followed immediately by 3 hours at 212° F.
(5) Mechanical Shock - 250 g's impact once in each of the 2 major axis.
(6) Vibration - 5 cps to 50 cps at .4 inches double amplitude displacement - 50 cps to 2000 cps at 35 g's - cycling time 60 minutes per axes on 2 major axes.
(7) Match sensitivity - 50 milliampere pulse for one second on each of the two matches - time between pulses 5½ seconds.
(8) Film was bad.
(9) All units fired with a 6 Volt DC source across a 1.3-ohm bridge circuit.

end ignition design, and the base plug end design offers higher average circuit resistance after firing; and

(2) N-1825B propellant will successfully withstand the environmental conditions outlined in Signal Corps Technical Requirement SCL-7564.

1.6.1.2 The gas volume produced by the generators was calculated using the actual pressure and temperature of the gas one minute after firing. The calculation was made in accordance with the following equation:

$$V = \frac{P_2 T_1 V_i}{P_1 T_2}$$

Where: V = Final volume of gas

P_2 = Pressure one minute after firing psig

P_1 = Standard pressure 15 psi

T_1 = Standard Temperature 273° K

T_2 = Temperature of gas one minute after firing °K

V_i = Initial volume of closed bomb = 1015 cc

Based on the gas volume data shown in Tables XXXIV and XXXV, the amount of propellant utilized in the 950 cc delay gas generators will be reduced to:

$$\frac{1140 \text{ cc}}{1.88 \text{ gm}} = \frac{950 \text{ cc}}{X \text{ gms}}$$

X = 1.57 gms, weight of propellant

1.6.2 The second environmental test series consisted of the evaluation of 36 gas generators utilizing base plug end ignition. Twelve of these units were to theoretically produce 950 cc of gas with an ignition delay of 200 milliseconds. The remaining 24 units were to theoretically produce 8000 cc of gas with 12 units each having instantaneous and 400 milliseconds delay ignition elements.

1.6.2.1 During evaluation of the first group of gas generators, it was determined that the gas generator delay ignition elements were deficient in that the ignitor material was not being reliably contained on the bridgewire causing occasional firing failures. In consideration of this deficiency, Unidynamics discontinued the evaluation of this group of gas generators, incorporated a minor modification to correct the deficiency and manufactured a second group of gas generators for evaluation. The modification consisted of incorporating a positive support, independent of component tolerance stack-up, to the paper disk retaining the ignitor charge.

1.6.2.2 The gas generators were subjected to various environmental conditions and test fired in the closed bomb. The test plan for these units, including the environmental conditioning sequence, is included as Appendix C. The test results are presented in Table XXXVII.

1.6.2.3 Several difficulties were encountered during the environmental conditioning and testing. These problems are discussed in the following paragraphs.

a. The first difficulty encountered was the failure of the end potting, 100 PBW Eccobond LV45, and 150 PBW No. 15 LV catalyst, to withstand 300° F for 168 hours. The potting had melted and run, thus lending itself ineffective for the remainder of the

TABLE XXXVII

FIRING TEST DATA FOR ENVIRONMENTAL UNITS

Note: All units fired with a 6 VDC source across a 1.3-ohm bridge circuit.

Serial No.	Output Size (cc)	Delay Ignition Element	Test Temp. (^oF)	Delay Time (ms)	Pressure Chamber No. 1 Peak Pressure (psi)	Pressure Chamber No. 1 Time-To-Peak (ms)	Pressure Chamber No. 2 Peak Pressure (psi)	Pressure Chamber No. 2 Time-To-Peak (ms)
5 (1)	950	200 ms	-65	227	6000 +	227	280	325
15 (1)	8000	Instant.	-65	N/A	6000 +	11	310	150
7 (1)	950	200 ms	-65	233	6000 +	233	450	320
10 (1)	8000	Instant.	-65	N/A	6000 + (3)	13	265	70
8 (1)	950	200 ms	-65	(4)	(4)	(4)	(4)	(4)
4 (1)	8000	Instant.	-65	N/A	6000 + (3)	8	300 (5)	150 (5)
6 (2)	950	200 ms	165	165	1625	165	230	450
4 (2)	8000	400 ms	-65	360	3000 + (3)	390	400	(6)
12 (2)	950	200 ms	165	152	1425	152	240	400
7 (2)	8000	400 ms	-65	380	3000 +	390	365	500

(1) End potting material = Stycast 2651
(2) End potting material = RTV 731
(3) Grain trap expelled
(4) Unit did not fire; bridgewire circuit open after fire pulse
(5) No picture obtained due to defective film; values are visual readings from scope
(6) No data obtained; scope triggered from pressure rise.

TABLE XXXVII (CON'T)

FIRING TEST DATA FOR ENVIRONMENTAL UNITS

Note: All units fired with a 6 VDC source across a 1.3-ohm bridge circuit.

Serial No.	Output Size (cc)	Delay Ignition Element	Test Temp. (°F)	Delay Time (ms)	Pressure Chamber No. 1 Peak Pressure (psi)	Pressure Chamber No. 1 Time-To-Peak (ms)	Pressure Chamber No. 2 Peak Pressure (psi)	Pressure Chamber No. 2 Time-To-Peak (ms)
12(1)	8000	400 ms	-65	387	7600	400	395	500
12(1)	8000	Instant.	Amb.	N/A	1100	16	(4)	(4)
10(1)	950	200 ms	165	170	5000	170	320	270
6(1)	8000	Instant.	-65	N/A	6000	18	365	100
3(1&2)	8000	Instant.	165	N/A	1100	3	420	200
6(1&2)	8000	400 ms	165	300	950(3)	310	300	440
2(1&2)	950	200 ms	165	150	1450	150	240	470
9(1&2)	8000	400 ms	165	335	1000	350	290	460
3(1&2)	950	200 ms	165	170	1450	175	250	480
13(1&2)	8000	400 ms	165	280	3000(3)	280	445	400

(1) End potting material = RTV 731
(2) Test fixture nozzle removed
(3) Grain trap expelled
(4) No data obtained; scope checked and recalibrated

TABLE XXXVII (CON'T)

FIRING TEST DATA FOR ENVIRONMENTAL UNITS

Note: All units fired with a 6 VDC source across a 1.3-ohm bridge circuit.

					Pressure Chamber No. 1		Pressure Chamber No. 2	
Serial No.	Output Size (cc)	Delay Ignition Element	Test Temp. (°F)	Delay Time (ms)	Peak Pressure (psi)	Time-To-Peak (ms)	Peak Pressure (psi)	Time-To-Peak (ms)
4(1&2)	950	200 ms	165	162	1500	162	415	240
9(1&2)	8000	Instant.	165	N/A	1000(3)	2	490	150
14(1&2)	8000	Instant.	165	N/A	3000 +	3	700	30
9(1&2)	950	200 ms	-60	240	1250	240	270	480
11(1&2)	950	200 ms	-60	190	1500	190	260	450
1(1&2)	8000	400 ms	-60	340	1000(3)	340	210	700
2(1&2)	8000	400 ms	-60	380	950(3)	380	320	640
13(1&2)	950	200 ms	-60	(4)	(4)	(4)	(4)	(4)
5(1&2)	8000	400 ms	-60	410	1050	410	(5)	(5)
7(1&2)	8000	Instant.	-60	N/A	1100(3)	14	490	180

(1) End potting material = RTV 731
(2) Test fixture nozzle removed
(3) Grain trap expelled
(4) Unit failed to fire
(5) No data obtained; defective trigger cable

TABLE XXXVII (CON'T)

FIRING TEST DATA FOR ENVIRONMENTAL UNITS

Note: All units fired with a 6 VDC source across a 1.3-ohm bridge circuit.

Serial No.	Output Size (cc)	Delay Ignition Element	Test Temp. (°F)	Delay Time (ms)	Pressure Chamber No. 1 Peak Pressure (psi)	Pressure Chamber No. 1 Time-To-Peak (ms)	Pressure Chamber No. 2 Peak Pressure (psi)	Pressure Chamber No. 2 Time-To-Peak (ms)
8(1&2)	8000	Instant.	-60	N/A	1000(3)	45	320	260
11(1&2)	8000	Instant.	-60	N/A	(4)	(4)	40	900
13(1&2)	8000	Instant.	165	N/A	1350(3)	8	(6)	(6)
8(1&2)	8000	400 ms	165	280	(3 & 5)	(5)	280	640
10(1&2)	8000	400 ms	165	320	1900(3)	320	360	460
11(1&2)	8000	400 ms	165	360	750	360	280	940

(1) End potting material = RTV 731
(2) Test fixture nozzle removed
(3) Grain trap expelled
(4) Scope trace duration 180 ms; no pressure recorded
(5) Scope failed to trigger

environmental conditioning. The units were reworked by removing the potting and closure disks, inserting new closure disks, and potting with a mixture of 100 PBW Stycast No. 2651 and 8 PBW No. 11 catalyst.

b. A second difficulty was encountered during environmental testing. Vibration of the units at 212° F introduced small voids in the end potting of 10 units allowing the leakage of small amounts of ignition powder. The leakage of the ignition powder apparently led to the ignition of one 8000 cc 400 millisecond delay unit during vibration. After voids in the potting were repaired, the environmental conditioning sequence was continued. Since only a small portion of ignition powder was lost from any unit, no additional ignition powder was added to compensate for the loss.

c. Two undesirable effects were noticed on the output end of the gas generators during the test firings.

(1) First, the grain trap was expelled from the case on some units. It was felt that this effect was due to excessive operating pressures inside the case or marginal holding capabilities of the end crimp. The excessive operating pressure possibility was investigated by recalculating the theoretical operating pressure and evaluating the output end of the units for possible restriction. The recalculation showed that the theoretical operating pressure was at a desirable level, but the evaluation of the output end indicated that the end potting could possibly be offering

enough resistance to increase the initial operating pressure. To eliminate this possibility, the potting (Stycast No. 2651, a rigid potting) and closure disks were removed and the holes of the grain trap were visually examined to insure no obstruction. A new closure disk was placed over the grain trap, and the periphery only was potted with Silastic RTV No. 731 silicone rubber. It is felt that the RTV silicone rubber applied to only the periphery of the closure disk caused essentially no increase to the initial operating pressure. Although the cause for possible excessive restriction was eliminated, the grain trap was expelled from several units during the remainder of the test firings. Based upon these findings, it is felt that the holding capability of the end crimp is marginal and must be improved.

(2) The second undesirable effect on the output end of the units was that the orificing area of the grain trap increased during the firing of the units. The heat and pressure produced by the propellant was in excess of the capability of the aluminum grain trap, which was only 1/32-inch thick in the area of the orifices. The grain trap should be redesigned for succeeding procurements.

d. A fourth problem was experienced with the test fixture. It will be noted in Table XXXVII that most of the initial firings exhibited extremely high peak pressures in the high pressure chamber. Based on an engineering evaluation, the nozzle in the test fixture

between the high and low pressure chambers was removed. In reviewing the reasons for incorporating the test fixture nozzle, it was determined that the original test fixture design did not contain the nozzle and that it was later added to insure an operating pressure high enough to stabilize burning of the propellant. However, since a grain trap was added to the gas generator for the purposes of containing the propellant within the case and stabilizing the burning of the propellant, the test fixture nozzle is no longer required.

1.6.2.4 Two 950cc gas generators failed to fire at -60° F. The resistance of both circuits in each of the gas generators was checked after firing and found to be greater than 50,000 ohms. The 200-millisecond delay matches were removed and examined. It was determined that the delay matches had not functioned completely. The delay matches were then sectioned and the internal components were examined. Examination showed that the base ignition charge (one milligram of basic lead styphnate) ignited but failed to ignite the transfer charge (five milligrams of A-1A). The function of the transfer charge is to ignite the delay element. Based on an engineering analysis, it was concluded that the transfer charge in the delay matches failed to ignite for one or both of the following reasons:

a. First, the one milligram base ignition charge was considered

to be marginal for igniting the transfer charge at -60° F.

b. Second, the appearance of the transfer charge in the failed delay matches indicated the possibility of excessive moisture in the powder.

To preclude the recurrence of failure caused by either of the above on future procurements, it is recommended that an ignition marginality test be conducted for the delay match and that extra precautionary measures be taken to insure that all powders are kept dry.

2. CONCLUSIONS

2.1 The results of the development and evaluation testing performed during this program demonstrated that Unidynamics' propellant N-1825B will successfully withstand the environmental conditions outlined in SCL 7564. In addition, N-1825B exhibited satisfactory batch-to-batch reproducibility, with more reproducible pressure-versus-time results than standard N-5 propellant. Preliminary tests indicate that an alternate propellant, B.F. Goodrich C-501, would be satisfactory for the environmental conditioning outlined in SCL 7564. However, the percentage of acidic gases in C-501 propellant was approximately twice that of N-1825B.

2.2 Unidynamics' standard UMH-1036 sealed match (instantaneous) will successfully withstand the environmental conditions outlined in SCL 7564. No further development work is required on the standard UMH-1036 sealed match for use in gas generators requiring instantaneous ignition. However, two problems were encountered with the delay match:

a. Ignition of the delay match is marginal at -60° F.

b. Delay times exceeded the specified ± five percent at temperatures ranging from -60° F to 160° F.

2.2.1 Additional development work should be conducted on the delay matches to insure reliable ignition at -60° F and to determine the feasibility of delay times within the specified ± five percent.

2.3 The basic gas generator design utilized throughout the development and testing program proved satisfactory for the application after two design improvements were incorporated: (1) positioning the matches on the base plug end and (2) the addition of a propellant grain trap. These design improvements resulted in higher circuit resistance after firing and increased reliability.

2.3.1 The addition of a propellant grain trap, as explained on page 56, maintains internal pressure inside the gas generator sufficiently high to maintain stable burning of the propellant grain irrespective of the pressure into which the generator gases are flowing. A proper ratio of trap exhaust area to grain burn area, commonly designated as Kn, is peculiar to any one propellant formulation and is a method of controlling the pressure and rate at which the propellant will burn.

2.3.2 Excellent resistance after firing performance was obtained with base-end ignition as can be seen in Tables XXXV and XXXVI, pages 64 and 65. With the matches located in the base plug, a minimum of exhaust gas residue is deposited on the match eyelet between the circuit pins, thereby eliminating the possibility of making an electrical path after the bridgewire has been consumed.

2.3.3 The capability of the unit to meet the requirement for no greater than ± five percent variation in peak pressure over the operating temperature range was not established during the test program. Additional testing, beyond the scope of this program, would be required to verify this parameter, as well as to assure that all materials used will withstand the operating temperatures and pressure.

.4 The closed bomb firing test fixture designed and fabricated during the development program proved basically satisfactory for use in the test program. However, it is felt that the test fixture nozzle restricted the pressure and shock impulses, resulting in high peak pressure readings in pressure Chamber No. 1. In addition, the test fixture nozzle was unnecessary after the nozzling feature was incorporated in the gas generators.

3. RECOMMENDATIONS

3.1 Based on the results obtained during the performance of this program and the requirements of SCL 7564, Unidynamics recommends that No. N-1825B be utilized in further development work on gas generators directed toward fulfilling the requirements of SCL 7564. This propellant yields more reproducible pressure-versus-time results than standard N-5 propellant, and is capable of withstanding the environmental conditions outlined in SCL 7564.

3.2 Unidynamics recommends that the UMH-1036 sealed match (instantaneous) be incorporated on all gas generators requiring instantaneous ignition. To eliminate the problems associated with the delay match (marginal ignition at -60° F and delay time variations in excess of the ± five percent), Unidynamics recommends that additional development work be conducted to insure reliable ignition at -60° F and to determine the feasibility of delay times within the specified ± five percent at temperatures ranging from -60° F to 165° F.

3.3 Unidynamics recommends additional development work on the gas generator design to insure that all materials used will withstand the operating temperatures and pressures. In addition, work directed toward achieving peak pressures and time to peak pressures within ± five percent will be required. The base plug end ignition and grain trap features should be continued on future units since they provide greater reliability in ignition of the propellant, more reproducibility in shot-to-shot performance, and greater circuit resistance after firing.

APPENDIX A

GAS OUTPUT TEST PROCEDURE

GAS OUTPUT TEST PROCEDURE

Equipment

1. Gram-atic Analytical Balance
2. Ignition wire for Parr peroxide bomb calorimeter
3. Modified Parr peroxide calorimeter bomb
4. Holding fixture or vise
5. Special wrench for tightening octagonal screw cap
6. Beaker (2000 ml) of boiling water

Materials

1. Propellant samples weighing 0.25 to 0.35 grams each

Procedure

1. Cut three propellant samples weighing 0.25 to 0.35 grams each from the lot of material to be tested.

2. Using a Gram-atic Analytical Balance, accurately weigh each sample to within 0.0001 gram.

3. Attach one end of the ignition wire to one terminal on the head of the gas evolution bomb (modified Parr peroxide bomb).

4. Wrap the wire around the first propellant sample several times; then attach the free end of the wire to the second terminal on the head of the bomb.

5. Place the cover of the bomb on the body and attach it securely by means of the screw cap. Place the bomb in the holding fixture or a vise and tighten the screw cap with the special wrench designed for that purpose.

6. Place the bomb behind a shield and attach the leadwires from the Parr ignition unit to the firing terminals.

7. Fire the sample.

8. Immerse the bomb in boiling water and allow it to stabilize in pressure. Record the pressure reading.

9. Calculate the gas output from the following equation:

$$V = \frac{2.32\,P - 8.5}{W}$$

where

V = gas output, cc/gram
P = pressure, psig
W = sample weight, grams 2.32 and 8.5 are constants for the bomb

10. Repeat the test with the second and third samples, and determine the average gas output.

APPENDIX B

THERMAL STABILITY TEST PROCEDURE

THERMAL STABILITY TEST PROCEDURE

Equipment

1. Gram-atic Analytical Balance
2. Two aluminum weighing dishes
3. Oven

Materials

1. Two each one-inch long strands of 3/8-inch-diameter extruded propellant.

Procedure

1. Cut two one-inch long strands of 3/8-inch diameter extruded propellant.

2. Using a Gram-atic analytical balance, accurately weigh each strand to within 0.0001 gram and record the weights.

3. Place each strand in an aluminum weighing dish and identify the dishes as #1 and #2.

4. Place the dishes in an oven heated to $300 \pm 5^{\circ}$ F and allow them to remain for 168 hours (one week).

5. Remove the dishes and allow the propellant strands to cool to room temperature.

6. Using the Gram-atic analytical balance, weigh each strand.

7. Subtract these weights from the original weights to obtain the actual weight loss caused by the 300° F exposure.

8. Divide each weight loss by the original weight to obtain the percentage weight loss.

9. Calculate the average percent weight loss for the two samples.

APPENDIX C

GAS GENERATOR TEST PROCEDURE

TEST PLAN
FOR
SIGNAL CORPS GAS GENERATORS

SIGNAL CORPS CONTRACT NO. DA-36-039-SC-87362

UNIDYNAMICS/PHOENIX DIVISION
UNIVERSAL MATCH CORPORATION
PHOENIX, ARIZONA

1. Introduction

This document outlines a proposed test plan for the evaluation of gas generators under Signal Corps Contract No. DA-36-039 SC-87362. Twelve generators of each of three types will be tested, making a total of 36 generators. The units will be subjected to environments and fired as outlined in paragraph 1.1. All tests are described in paragraphs 2.1 through 2.9.

1.1 Environmental Tests

All units (12 of each type) will be subjected to the following environments and tests in the order listed.

1. Bridgewire Resistance (Paragraph 2.1)
2. Radiographic Inspection (paragraph 2.2)
3. High Temp. Storage (paragraph 2.3)
4. Low Temp. Storage (paragraph 2.4)
5. Thermal Shock (paragraph 2.5)
6. High Temp. Mechanical Shock (paragraph 2.6)
7. Low Temp. Mechanical Shock (paragraph 2.6)
8. High Temp. Vibration (paragraph 2.7)
9. Low Temp. Vibration (paragraph 2.7)
10. Match Sensitivity (paragraph 2.8)
11. Bridgewire Resistance (paragraph 2.1)
12. Radiographic Inspection (paragraph 2.2)

*13. Firing (paragraph 2.9)

*Six units of each size will be fired at -60° F and six units of each size will be fired at 165° F

2.0 DESCRIPTION OF TESTS

2.1 Bridgewire Resistance

The bridgewire resistance of both matches in each generator will be measured and recorded.

2.2 Radiographic Inspection

Each unit will be X-rayed and examined for proper location of all components.

2.3 Accelerated Temperature Storage

The units will be subjected to 300 $\pm$ 5° F, humidity uncontrolled, for 168 hours.

2.4 Low Temperature Storage

The units will be subjected to -80 $\pm$ 5° F, humidity uncontrolled, for 72 hours.

2.5 Thermal Shock Storage

The units will be subjected to five cycles of thermal shock, each cycle consisting of three hours storage at -80 $\pm$ 5°F followed by three hours storage at 212 $\pm$ 5°F. The transient time from -80°F to 212°F will be less than five minutes.

2.6 Mechanical Shock

The units will be mounted in the holding fixtures and the fixtures mounted on the shock machine. The units and fixtures will be stabilized at temperature (either -80°F or +212°F). The units will then be submitted to a shock of 250 $\pm$ 25g with a rise time of 6 to

11 milliseconds along the longitudinal axis with the leadwire end up.

2.7 Vibration

The units will be mounted in the holding fixtures and the fixtures mounted on the vibration table. The units and fixtures will be stabilized at temperature (either -80° F or +212° F). The units will be subjected to a 50g vibration, thirty-minute sweep duration from 40 to 2000 cps along the longitudinal axis.

2.8 Match Sensitivity

Both bridgewires of the units being tested will be subjected to 10,000 electrical impulses of 50 milliamperes intensity and one second duration. The units will be allowed to cool 5.5 seconds between pulses.

2.9 Firing Test

The units will be fired using the firing circuit of Figure 2. For all generators, the entire bomb with the generator in place, may be stabilized at either -60° F or 165° F as called out in Paragraph 1.1. The bomb will then be removed from the temperature chamber and fired as soon as practical.

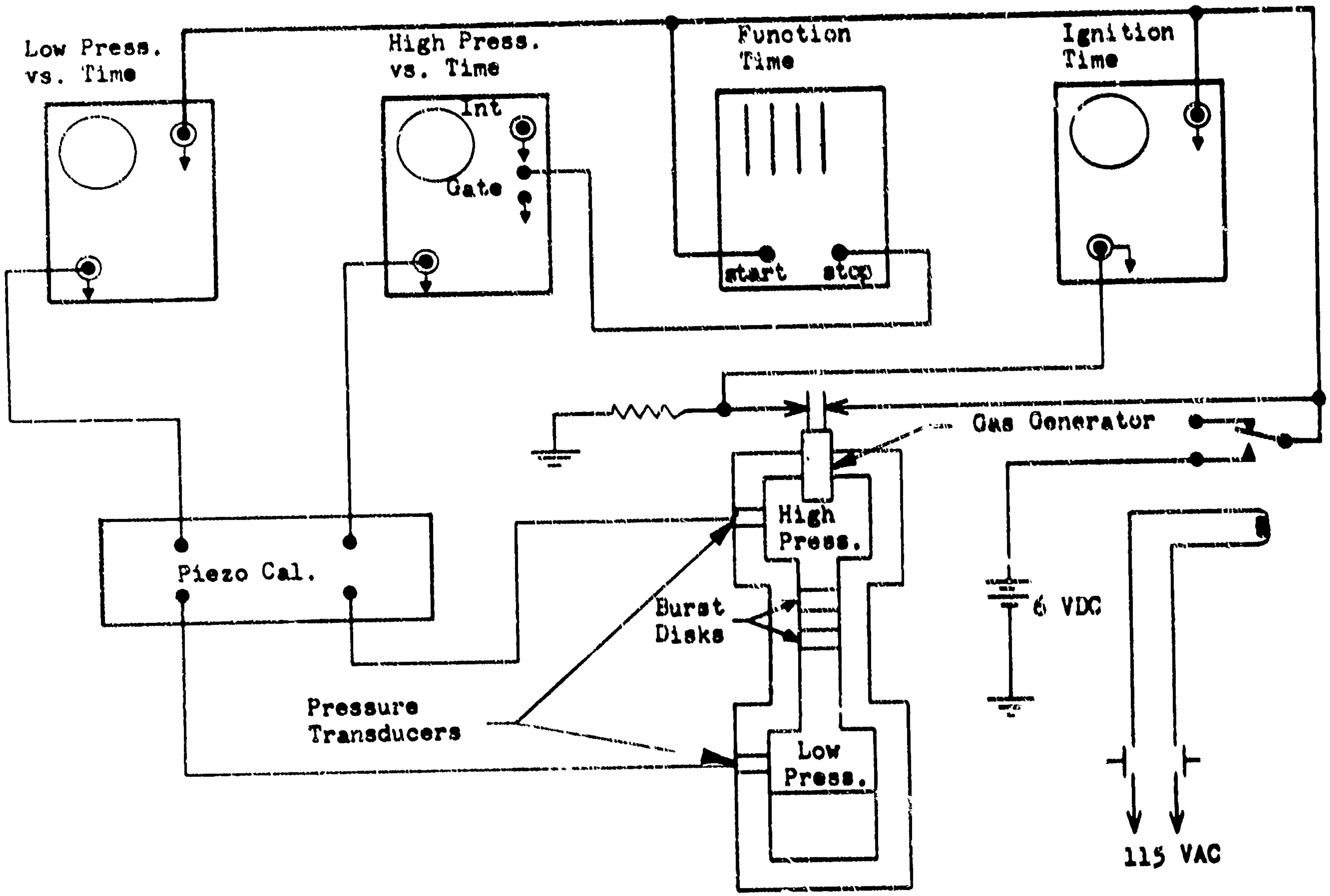

FIGURE 2. FIRING CIRCUIT SCHEMATIC

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13 ABSTRACT

This report describes the work conducted under Contract DA 36-039 SC-87362 with the U.S. Signal Supply Agency, consisting of a propellant investigation, gas generator design and development, and development and environmental testing of gas generators. (U)

The results of the propellant investigation indicated that one commercial propellant, B.F. Goodrich C-501, and a Unidynamics formulation N-1825B, exhibited the most satisfactory thermal stability and reproducible gas output and pressure-vs-time characteristics after conditioning at 300°F for 168 hours. However, N-1825B propellant was selected for use in the gas generator since it is easily furnished with center perforations and exhibits a low content of hydrochloric acid in its exaust gases. (U)

During gas generator design and development, sealed matches with delays of 0, 0.2, and 0.4 seconds were developed which provided outputs sufficient to ignite the propellant charge. In addition, the original design of the gas generators was modified to incorporate a grain trap nozzle and provide base plug end ignition. A satisfactory test fixture was fabricated for pressure-vs-time and output testing.(U)

Testing of the gas generators demonstrated that the hardware design and propellant formulation were satisfactory for the application. However, two problem areas were encountered: (1) Ignition of the 0.2 and 0.4-second delay matches was marginal at -60° F, and (2) delay burn times exceeded the specified ± five percent over the temperature range -60°F to 165° F. In addition, extensive development work beyond the scope of this program would be required to verify the specified ± five percent variation in peak pressure over the operating temperature range (U)

14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
1. Gas generators						
2. Propellant						
3. Flash Charge						
4. Electric match						
5. Delay match						
6 design						
7 development						
8 fabrication						
9 stable						
10 cartridge						

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SIGNAL CORPS TECHNICAL REQUIREMENT SCL 7564

DATED 11 AUGUST 1960

Work Period: July 1961 to May 1963

Task No. 1C6 22001A 053-02

RESEARCH AND DEVELOPMENT DIRECTED TOWARD THE DEVELOPMENT OF GAS GENERATORS

FINAL REPORT

Document No. D63-702

The object of this program is to develop gas generators covering an output range of 50 to 10,000 cc, with means of incorporating delay times from electrical pulse to propellant ignition of 0 -.4 seconds, with operating temperatures from 65° F to 212° F and storage temperatures from -80° F to 300° F.

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